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SCOUR PROTECTION FOR DAM NUMBER <3> MONONGAHELA RIVER  
PENNSYLVANIA HYDRAU (U) ARMY ENGINEER WATERWAYS  
EXPERIMENT STATION VICKSBURG MS HYDRA R L STOCKSTILL

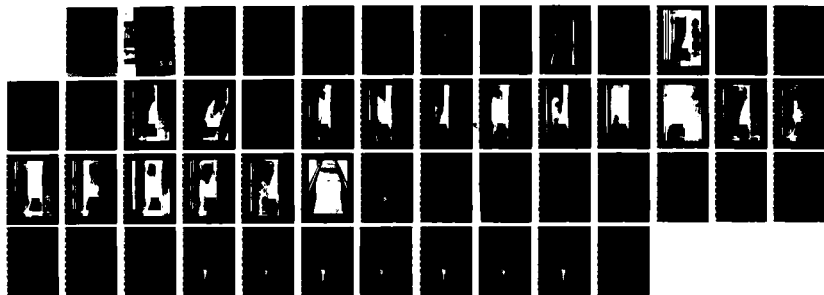
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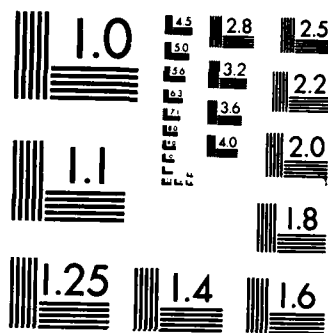
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# SCOUR PROTECTION FOR DAM NO. 3 MONONGAHELA RIVER, PENNSYLVANIA

Hydraulic Model Investigation

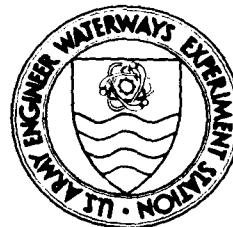
by

Richard L. Stockstill

Hydraulics Laboratory

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DEPARTMENT OF THE ARMY  
Waterways Experiment Station, Corps of Engineers  
PO Box 631, Vicksburg, Mississippi 39180-0631



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HYDRAULICS



LABORATORY

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## PREFACE

The model investigation reported herein was authorized by the Office, Chief of Engineers (OCE), US Army, on 8 December 1983 at the request of the US Army Engineer District, Pittsburgh (ORP).

The studies were conducted by personnel of the Hydraulics Laboratory (HL), US Army Engineer Waterways Experiment Station (WES), during the period December 1985 to April 1986 under the direction of Messrs. F. A. Herrmann, Jr., Chief, HL, and J. L. Grace, Jr., Chief of the Hydraulic Structures Division. The tests were conducted by Mr. R. L. Stockstill, Locks and Conduits Branch, under the supervision of Mr. J. F. George, Acting Chief of the Locks and Conduits Branch. This report was prepared by Mr. Stockstill.

The model was constructed by Mr. Willard Landers under the supervision of Mr. Sid Leist, Engineering and Construction Services Division.

Messrs. Bruce McCartney of OCE; Laszlo Varga and David D. Pattison of the US Army Engineer Division, Ohio River; and Ed Kovanic, Robert W. Schmitt, Joe Coletti, Ray Povirk, and Joe Violi of ORP visited WES during the course of the model study to observe model operation and correlate results with design studies.

COL Allen F. Grum, USA, was the previous Director of WES. COL Dwayne G. Lee, CE, is the present Commander and Director. Dr. Robert W. Whalin is Technical Director.



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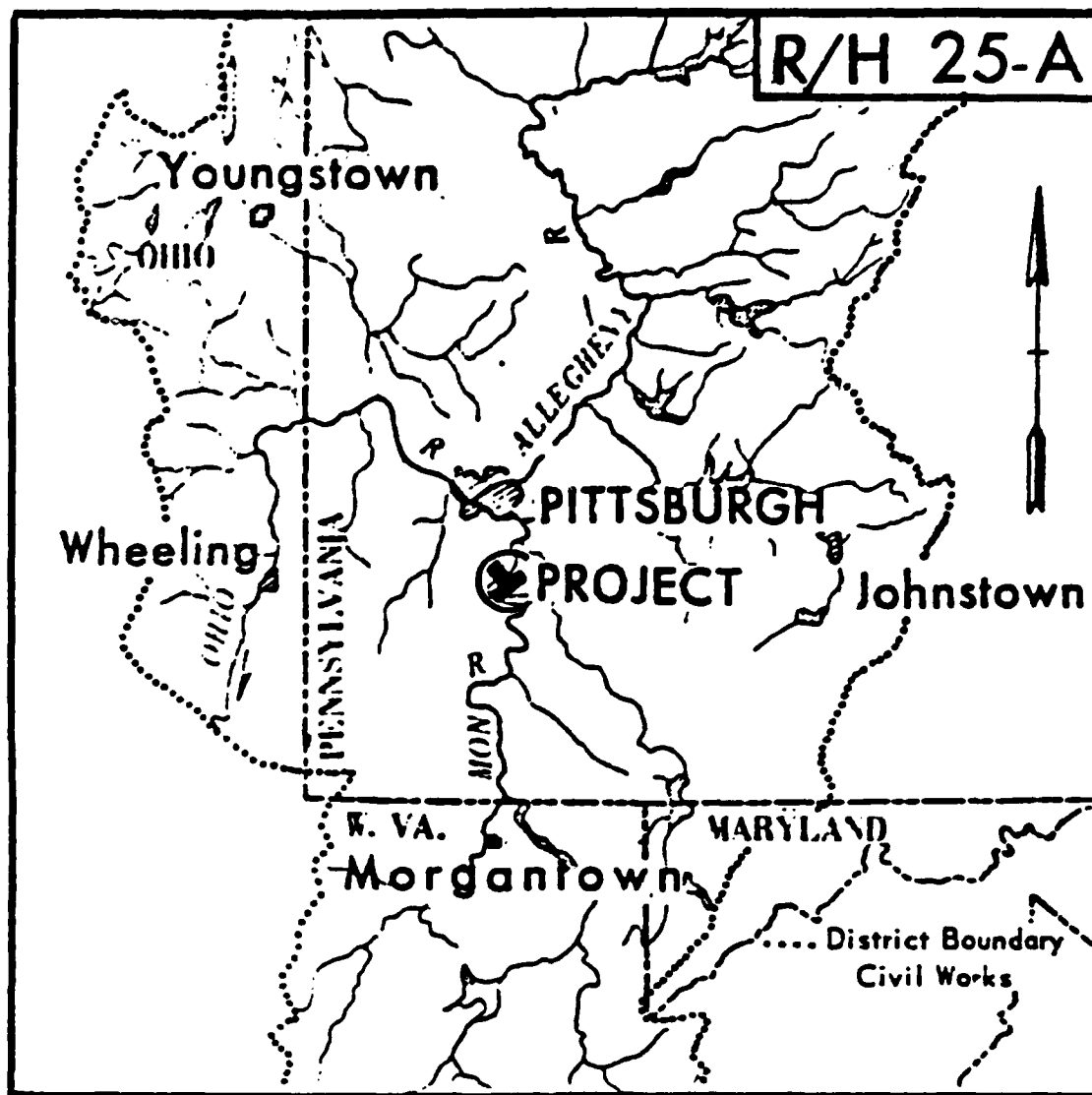
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# CONVERSION FACTORS, NON-SI TO SI (METRIC)

## UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
cubic feet	0.02831685	cubic metres
feet	0.3048	metres
inches	2.54	centimetres
miles (US statute)	1.609347	kilometres



## VICINITY MAP

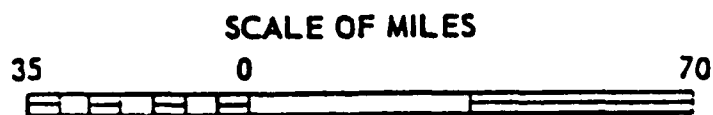


Figure 1. Vicinity map



SCOUR PROTECTION FOR DAM NO. 3,  
MONONGAHELA RIVER, PENNSYLVANIA  
Hydraulic Model Investigation

PART I: INTRODUCTION

Background

1. Lock and Dam No. 3, Monongahela River is located south of Pittsburgh, Pennsylvania, 23.8 miles\* from the mouth of the river (Figure 1). Originally, the dam was constructed as a gated concrete structure founded on timber piles and stone filled timber cribbing. It was later modified into an uncontrolled fixed-crest dam as shown in Figure 2. The dam is 670 ft long and has an 18-ft-wide pier located 397.5 ft from the river wall of the lock (Figure 2). The dam has a 1-ft chamfer on the upstream edge of the 5-ft-wide weir crest (el 726.9\*\*) and a 13-ft-long horizontal spillway apron (el 719.0) with no energy dissipator appurtenances.

2. A diver's inspection dated 13 July 1983 found that the spillway apron was undercut in several places and at some locations the cribbing was exposed. There is concern that if the downstream face of the dam is not protected against future scour the structure's integrity may be jeopardized.

Purpose of Model Study

3. The US Army Engineer District, Pittsburgh (ORP), requested the US Army Engineer Waterways Experiment Station to design, construct, and test a section model of Dam No. 3, Monongahela River. The purpose of the model study was to develop a scour protection plan to prevent structural damage to the dam. In order to develop an adequate plan of scour protection, it is necessary to determine the flow conditions at which scour would be most likely to occur.

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\* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

\*\* All elevations (el) and stages cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD).

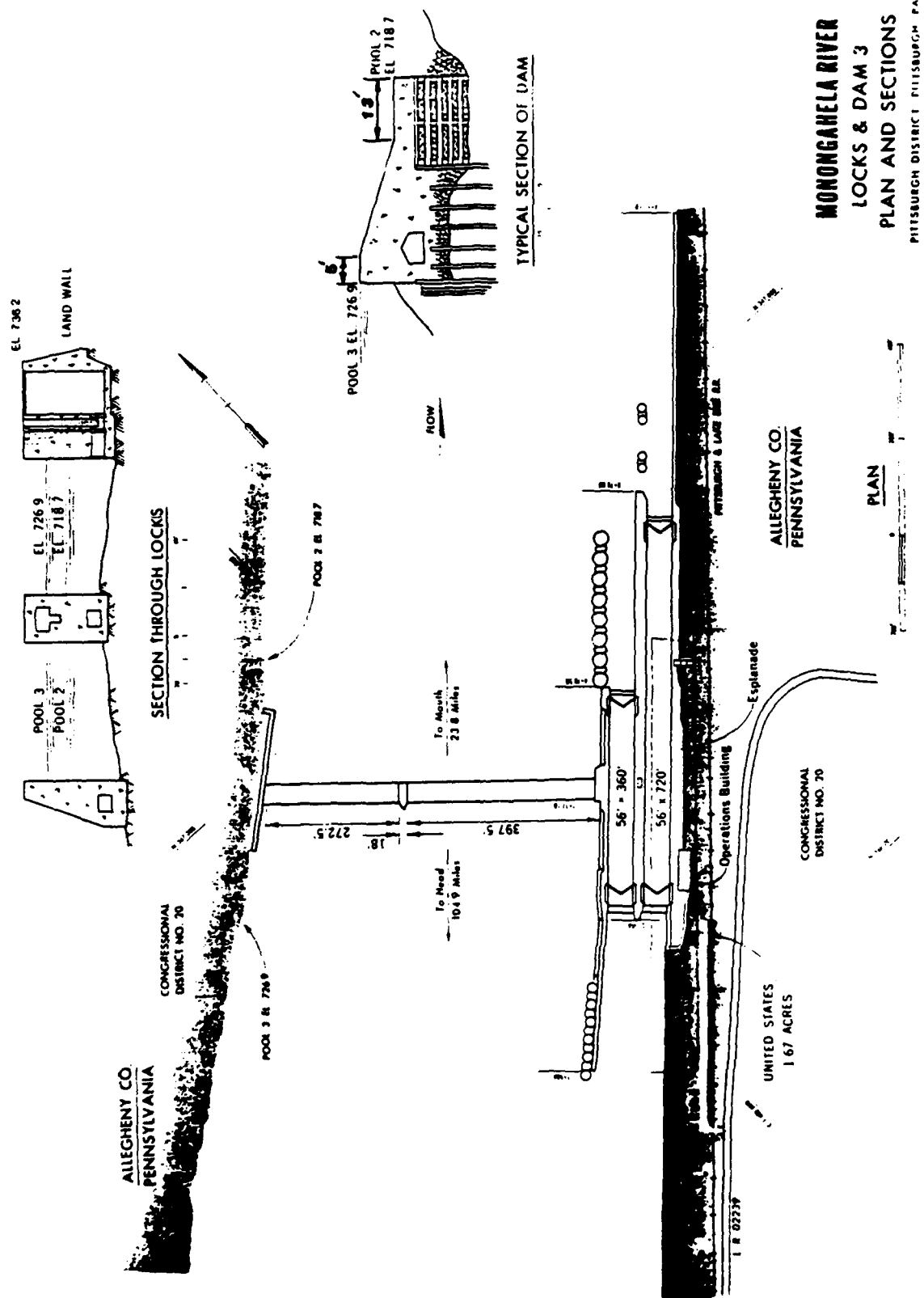


Figure 2. Plan and sections

## PART II: THE MODEL

### Description

4. The 1:25-scale section model, shown in Figure 3, reproduced a 50-ft-long section of the uncontrolled 670-ft-long, fixed-crest weir and spillway apron, the proposed scour protection material, 200 ft of topography upstream from the structure, and 400 ft of the exit channel. The fixed-crest weir and the spillway apron were fabricated of sheet metal and the upstream topography was constructed of plastic-coated plywood. A 125-ft-long section of the exit channel immediately downstream of the dam was molded with crushed stone riprap and pea gravel, and the remaining downstream topography was built of plastic-coated plywood.

### Model Appurtenances

5. Water used in operation of the models was supplied by a circulating system. Discharges in the model, measured with venturi meters installed in the inflow lines, were baffled when entering the model. Water-surface elevations and soundings over the sand and riprap beds were measured with point gages. Velocities were measured with Nixon current meters mounted to permit measurement of flow from any direction and at any depth. The tailwater in the lower end of the model was maintained at the desired depth by means of an adjustable tailgate. Different designs, along with various flow conditions, were recorded photographically.

### Scale Relations

6. The accepted equations of hydraulic similitude, based on the Froudian criteria, were used to express mathematical relations between the dimensions and hydraulic quantities of the model and prototype. General relations for the transference of model data to prototype equivalents are presented below:



Figure 3. Side view of type 2 riprap plan

<u>Characteristic</u>	<u>Dimension*</u>	<u>Model:Prototype</u>
Length	$L_r$	1:25
Area	$A_r = L_r^2$	1:625
Velocity	$V_r = L_r^{1/2}$	1:5
Discharge	$Q_r = L_r^{5/2}$	1:3,125
Volume	$V_r = L_r^3$	1:15,625
Weight	$W_r = L_r^3$	1:15,625
Time	$T_r = L_r^{1/2}$	1:5

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\*Dimensions are in terms of length.

Model measurements of discharge, water-surface elevations, and velocities can be transferred quantitatively to prototype equivalents by means of the scale relations. Experimental data also indicate that the model-to-prototype scale ratio is valid for scaling stone in the sizes used in this investigation.

### PART III: TESTS AND RESULTS

7. Initial tests were conducted with the type 1 riprap plan (Plate 1) which consisted of 4- to 5-ft-diameter stones placed on a 1V on 3H downward slope beginning at el 717 (2 ft below the spillway apron) and terminating at el 703. Soundings taken in May 1982 were furnished by ORP and indicated that el 703 was representative of the existing river bottom 41 ft downstream from the dam. Prototype flows were tested by setting the appropriate unit discharge in the section model. Rating curves for flow over the dam only are shown in Plate 2. The actual prototype rating curves account for flow over the locks, esplanade, and abutment when large discharges occur. These curves were not applicable to the model for the large discharges since only a section of the dam was reproduced.

8. A plunging jet flow was observed with discharges up to 125,000 cfs (unit discharge,  $q$ , of 186.6 cfs/ft of width) over the dam with minimum tailwater conditions and for discharges up to 70,000 cfs (unit  $q$  of 104.5 cfs/ft) over the dam for maximum tailwater conditions. Photographs of flow conditions with discharges of 15,000 cfs (unit  $q$  of 22.4 cfs/ft), 50,000 cfs (unit  $q$  of 74.6 cfs/ft), 70,000 cfs, and 125,000 cfs with minimum tailwater conditions are shown in Photos 1-4. Flow conditions with a discharge of 70,000 cfs and maximum tailwater conditions are shown in Photo 5. This illustrates a riding jet that flows along the surface of the tailwater. This condition also occurs for discharges greater than 125,000 cfs with minimum tailwater conditions. The riding jet is shown in Photos 6 and 7 for discharges of 135,000 cfs (unit  $q$  of 201.5 cfs/ft) and 185,000 cfs (unit  $q$  of 276.1 cfs/ft) with minimum tailwater. A discharge of 185,000 cfs with minimum tailwater was the largest discharge shown on the rating curve furnished by ORP for flow over the dam only.

9. The stability of the type 1 riprap plan, described in paragraph 7, was tested for discharges up to 185,000 cfs with minimum and maximum tailwater conditions and was stable for each condition observed. Since the 4- to 5-ft-diameter stone of the type 1 riprap plan remained stable, additional tests were conducted to evaluate the adequacy of smaller diameter stone. The 4- to 5-ft-diameter stones were replaced with 3- to 4-ft-diameter stones (type 2 riprap plan shown in Plate 3). The type 2 riprap was offset 2 ft below the spillway apron and sloped downward 1V on 3H to el 703. Tests revealed that

the riprap was stable for discharges up to 185,000 cfs. Water-surface profiles and velocities obtained with the type 2 riprap plan in place are shown in Plates 4-10. The maximum velocity exiting the spillway apron was 21.5 ft/sec and occurred with a discharge of 50,000 cfs, Plate 5.

10. The type 2 riprap plan was replaced with the type 3 riprap plan which consisted of a blanket thickness of 54 inches with an average stone diameter,  $D_{50}$ , of 27 inches placed in a similar manner to the type 2 riprap plan shown in Plate 3. The type 3 riprap plan was unstable for discharges equal to and greater than 70,000 cfs with minimum tailwater conditions. Tests were not conducted with the riprap offset more than 2 ft, as in previous model studies, due to the relatively small thickness of the spillway apron, 3.5 ft.

11. At this point in the testing program, ORP requested that tests be conducted with a level blanket of riprap downstream of the spillway apron. There was concern that some areas downstream of the dam may not have scoured as severely as others and that a level blanket of scour protection would be required in these areas. Tests were conducted with 3- to 4-ft-diameter stones (Type 4 riprap plan) and 4- to 5-ft-diameter stones (Type 5 riprap plan) offset 2 ft below the spillway apron and placed horizontally downstream of the dam for 50 ft and then sloped downward 1V on 3H. Both the Types 4 and 5 riprap plans were unstable. The high velocity flow jet exiting the spillway apron was not able to expand and subsequently the hydraulic jump formed farther downstream directly attacking and displacing the riprap.

12. The type 6 scour protection, plan which consisted of grout-filled fabric bags (20 ft by 6.75 ft by 2.75 ft) placed horizontally downstream of the spillway apron for 46.75 ft followed by 4- to 5-ft-diameter stones sloped downward 1V on 3H, was tested next. The horizontal blanket of grout-filled fabric bags consisted of two rows of bags with the longitudinal axis placed parallel to the direction of flow followed by one row of bags placed perpendicular to the direction of flow. Tests with the type 6 scour protection plan indicated that the plunging jet that occurred between discharges of 50,000 cfs and 70,000 cfs with minimum tailwater conditions displaced the row of bags placed perpendicular to the direction of flow and many of the 4- to 5-ft-diameter stones.

13. Since the plunging jet flow directly attacked the grout-filled bags placed perpendicular to the flow, these bags were removed reducing the horizontal length of the blanket by 6.75 ft. Also the 4- to 5-ft-diameter stones

placed on the 1V on 3H downward slope were replaced with grout-filled fabric bags. This was designated the type 7 scour protection plan and is shown in Plate 11 and Figure 4. Tests were conducted with the type 7 scour protection plan and the plan was stable for all flow conditions observed. Photographs for discharges of 15,000 cfs, 50,000 cfs, 70,000 cfs, 125,000 cfs, 135,000 cfs, and 185,000 cfs with minimum tailwater conditions and for 70,000 cfs with maximum tailwater conditions are presented in Photos 8-14. Water-surface profiles and velocities obtained for various flow conditions with the type 7 scour protection plan are shown in Plates 12-18. Velocities exiting the spillway apron increased with the type 7 scour protection plan as seen by comparing Plates 12 and 13 with Plates 4 and 5. The maximum velocity observed exiting the spillway apron was 25.8 ft/sec and occurred with a discharge of 15,000 cfs, Plate 12. The maximum velocity over the type 7 scour protection was 11.2 ft/sec and was observed with a discharge of 125,000 cfs, Plate 16.

14. If the topography downstream of the structure dictates that scour protection materials will be placed horizontally, the type 7 plan will be adequate. However, placing a horizontal blanket of scour protection downstream of the structure adversely affects the exiting flow conditions. Figure 5 shows how the section model was utilized to construct both the type 2 and type 7 scour protection plans. A photograph illustrating simultaneous flow conditions for a discharge of 50,000 cfs and a minimum tailwater condition with both the type 2 riprap plan and the type 7 scour protection plan is presented in Photo 15. The photograph shows that the toe of the submerged hydraulic jump formed over the spillway apron with the type 2 riprap plan whereas with the type 7 scour protection plan, the toe of the free hydraulic jump formed approximately 40 ft downstream of the structure. This indicates that supercritical flow will exist over the horizontal blanket of bags and this will allow lateral flow concentration to or from adjacent deeper areas depending on tailwaters. Note that the false wall provided in the section model prevented such adverse and undesirable flow conditions which would require a full width model of the entire structure and exit area for proper investigation.



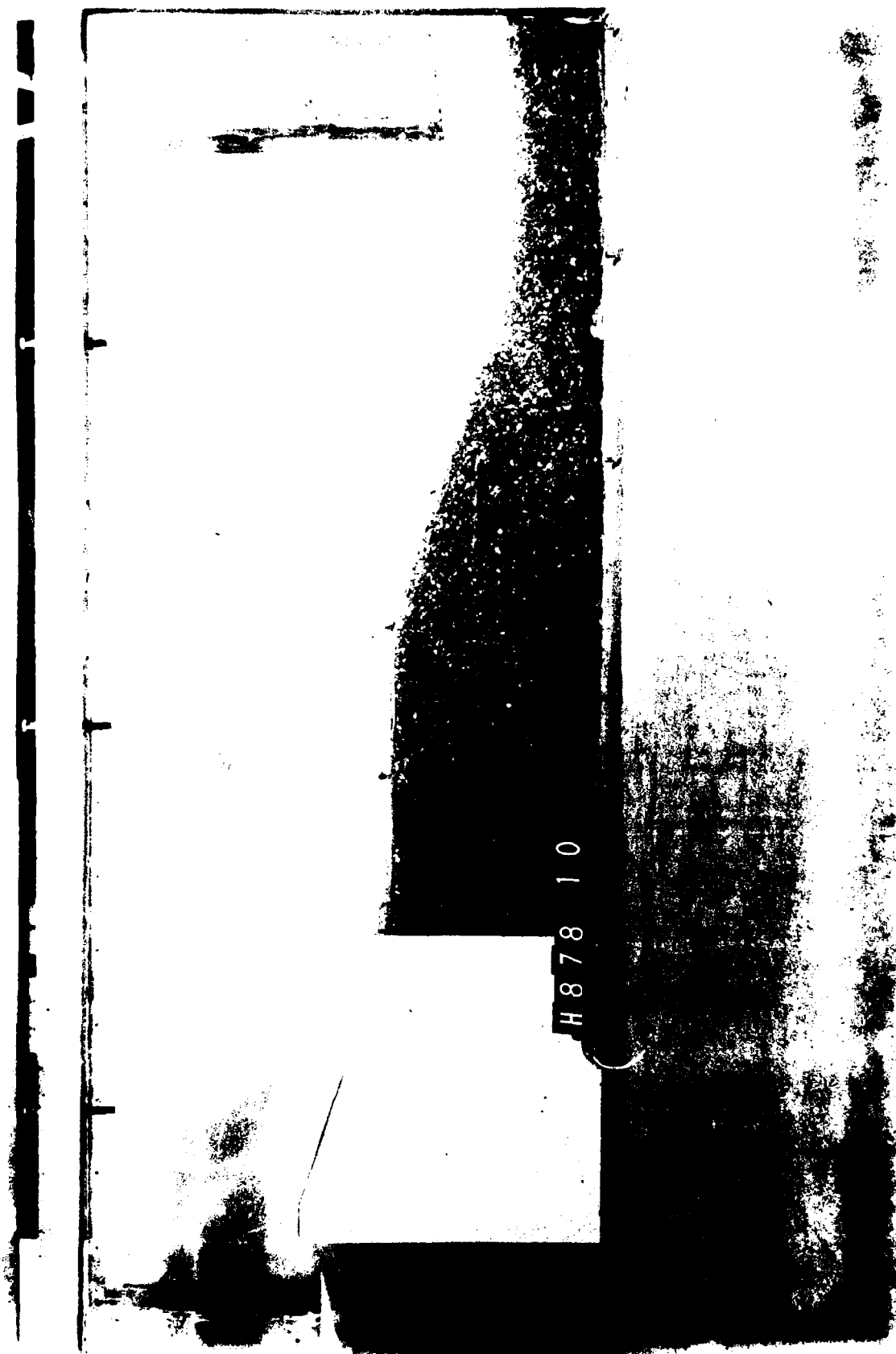


Figure 4. Side view of type 7 scour protection plan



Figure 5. Side view of type 2 riprap plan (foreground) and  
type 7 scour protection plan (background)

#### PART IV: SUMMARY AND RECOMMENDATIONS

15. Section model tests of Dam No. 3, Monongahela River revealed that a high velocity jet exits near the floor of the spillway apron for discharges, over the dam only, up to 125,000 cfs with minimum tailwater conditions and for discharges up to 70,000 cfs (over the dam) with maximum tailwater conditions. These jet flows and lateral flow concentrations probably caused unsymmetrical flow distribution and the severe scour experienced immediately downstream of the structure. Scour protection plans were developed for symmetrical distributions of discharges up to 185,000 cfs using various sizes and configurations of materials. The type 2 riprap plan (3- to 4-ft-diameter stones) was found to be stable for all symmetrical flow conditions observed when offset 2 ft below the spillway apron and sloped downward 1V on 3H. The type 7 scour protection plan which consisted of grout-filled fabric bags (20 ft by 6.75 ft by 2.75 ft) was also found to be stable for all symmetrical flow conditions observed when offset 2 ft below the spillway apron and placed horizontally for 40 ft downstream of the structure and then sloped downward 1V on 3H.

16. The flow conditions associated with the type 7 scour protection plan for discharges around 50,000 cfs are considered undesirable. If the type 7 scour protection plan is used downstream of the dam in some locations and the type 2 riprap plan in other locations, the grout-filled bags should be used to transition from the type 7 scour protection plan back to the type 2 riprap plan. However, adverse flow conditions will occur in the exit area which could result in the instability of the riprap or the grout-filled bags depending on tailwaters and flow distributions other than symmetrical. To eliminate this transition, it is recommended that necessary excavation or fill should be performed so that either the type 2 riprap plan or type 7 scour protection plan can be constructed for the full length of the dam.

17. Both plans of protection, the 3- to 4-ft-diameter stones and/or the 20 ft by 6.75 ft by 2.75 ft grout-filled fabric bags, will be subject to extremely turbulent flow and will require a properly designed granular filter(s) large enough to prevent piping through the voids of the large rock or grout-filled bags. As a minimum, a filter thickness of 36 inches with a  $D_{50}$  size of 18 inches is preferred immediately beneath the 3- to 4-ft-diameter stones or the 20 ft by 6.75 ft by 2.75 ft grout-filled fabric bags.

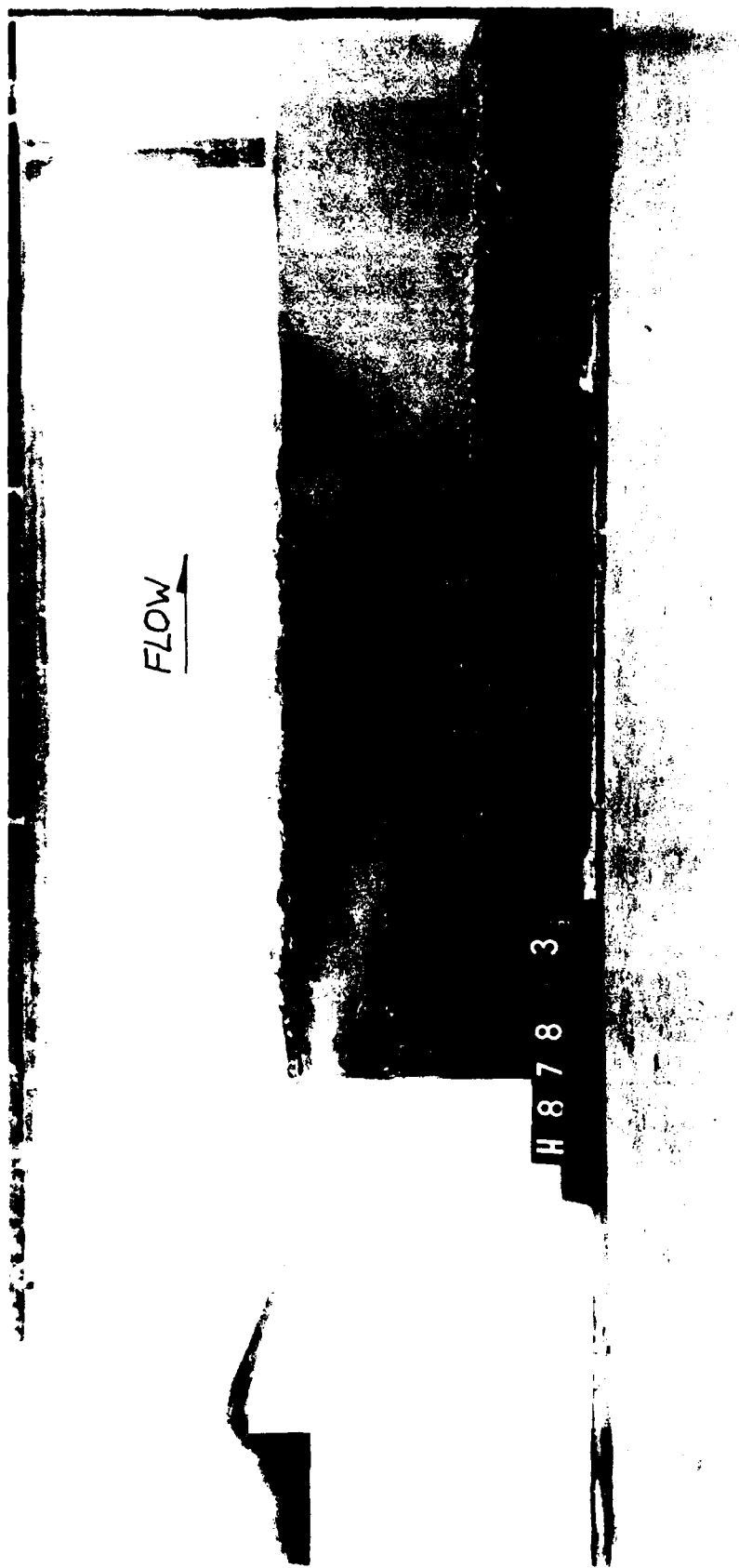


Photo 1. Flow conditions with Type 2 riprap plan; discharge 15,000 cfs, tailwater el 722.6

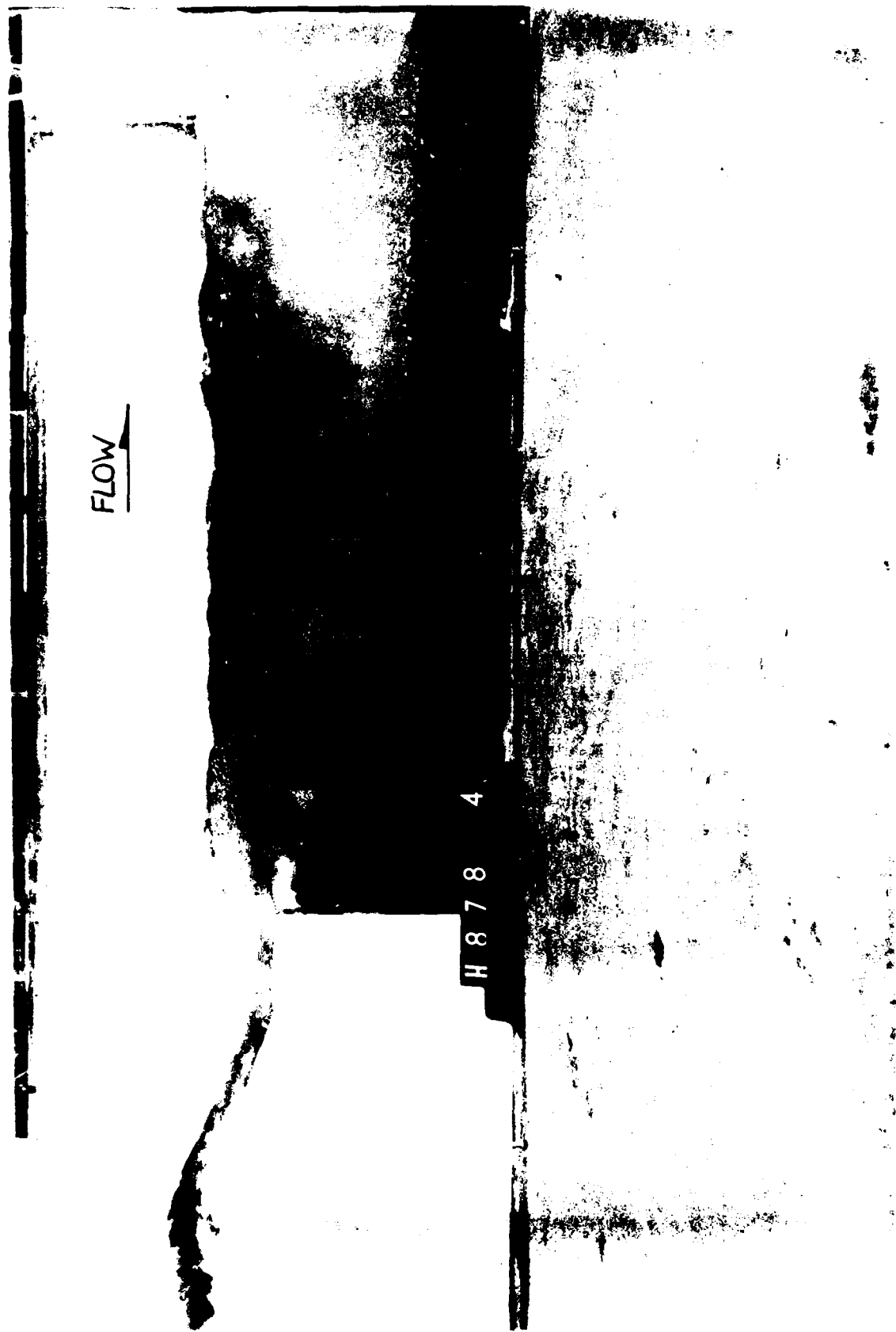


Photo 2. Flow conditions with Type 2 riprap plan; discharge 50,000 cfs, tailwater el 728.1

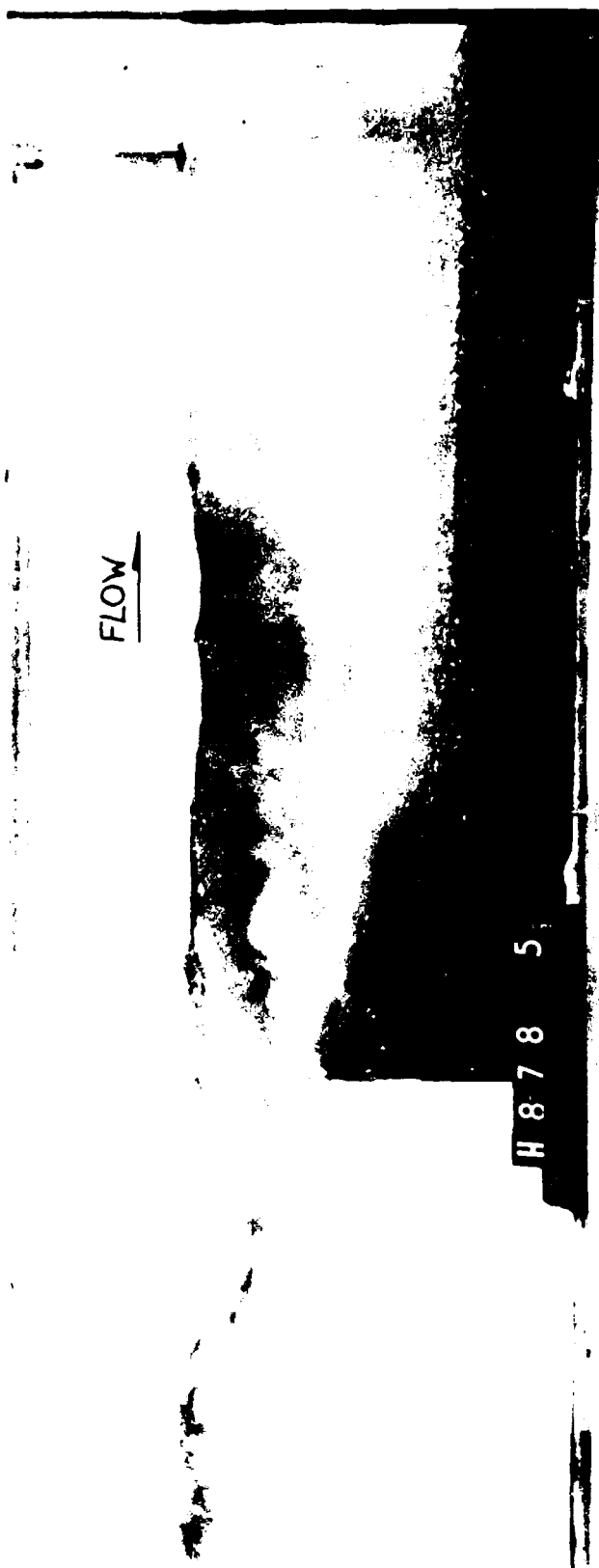


Photo 3. Flow conditions with Type 2 riprap plan; discharge 70,000 cfs, tailwater el 731.2

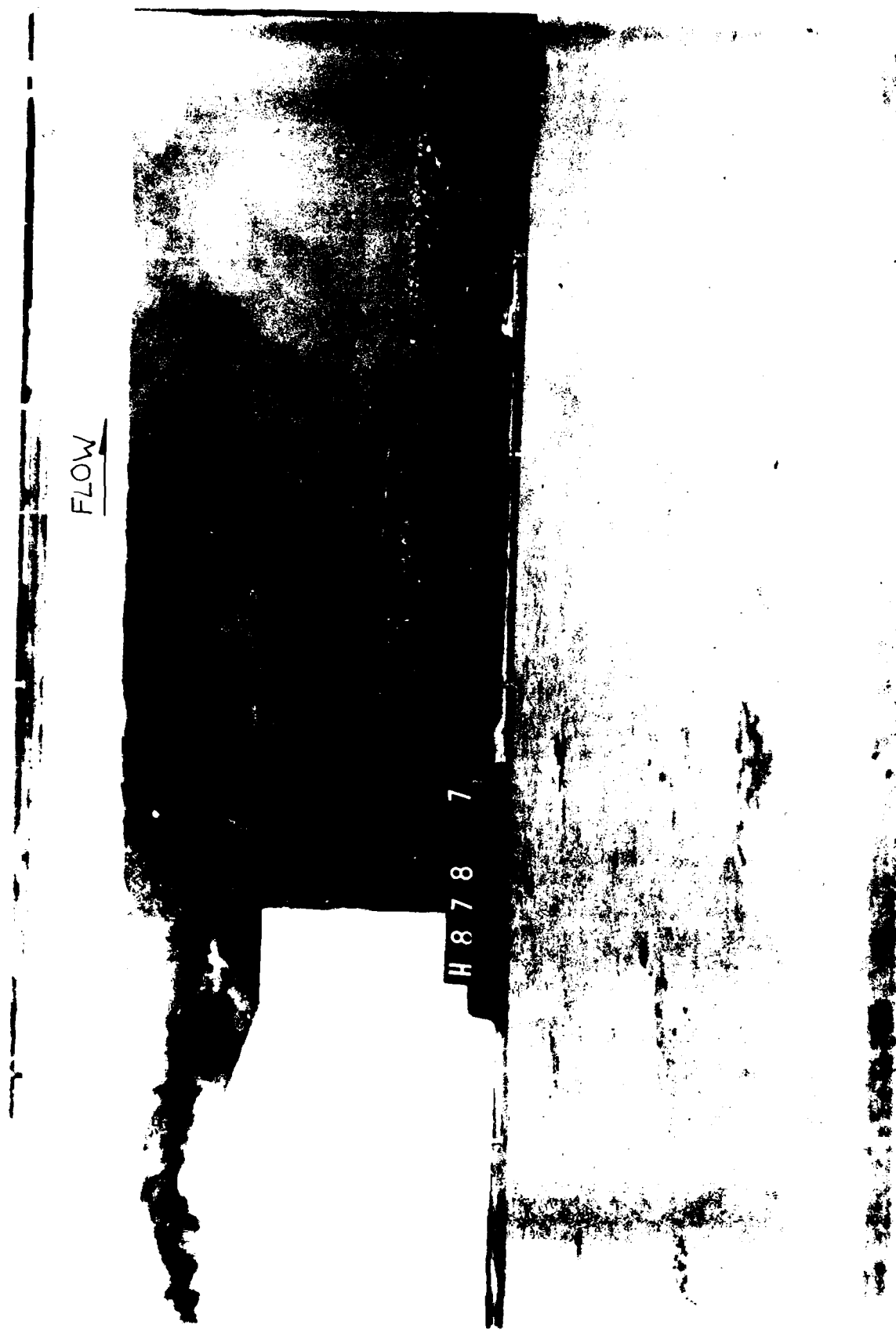


Photo 4. Flow conditions with Type 2 riprap plan; discharge 125,000 cfs, tailwater el 739.0

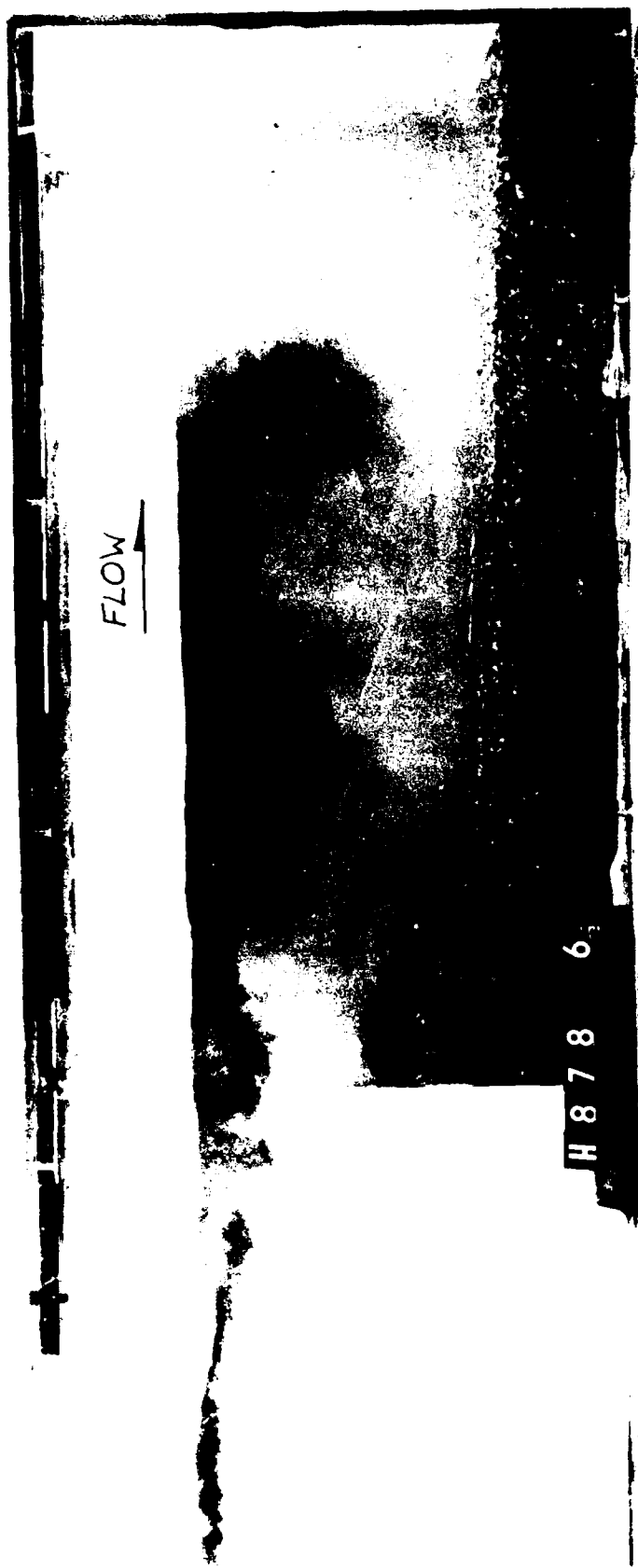


Photo 5. Flow conditions with Type 2 riprap plan; discharge 70,000 cfs, tailwater el 737.1



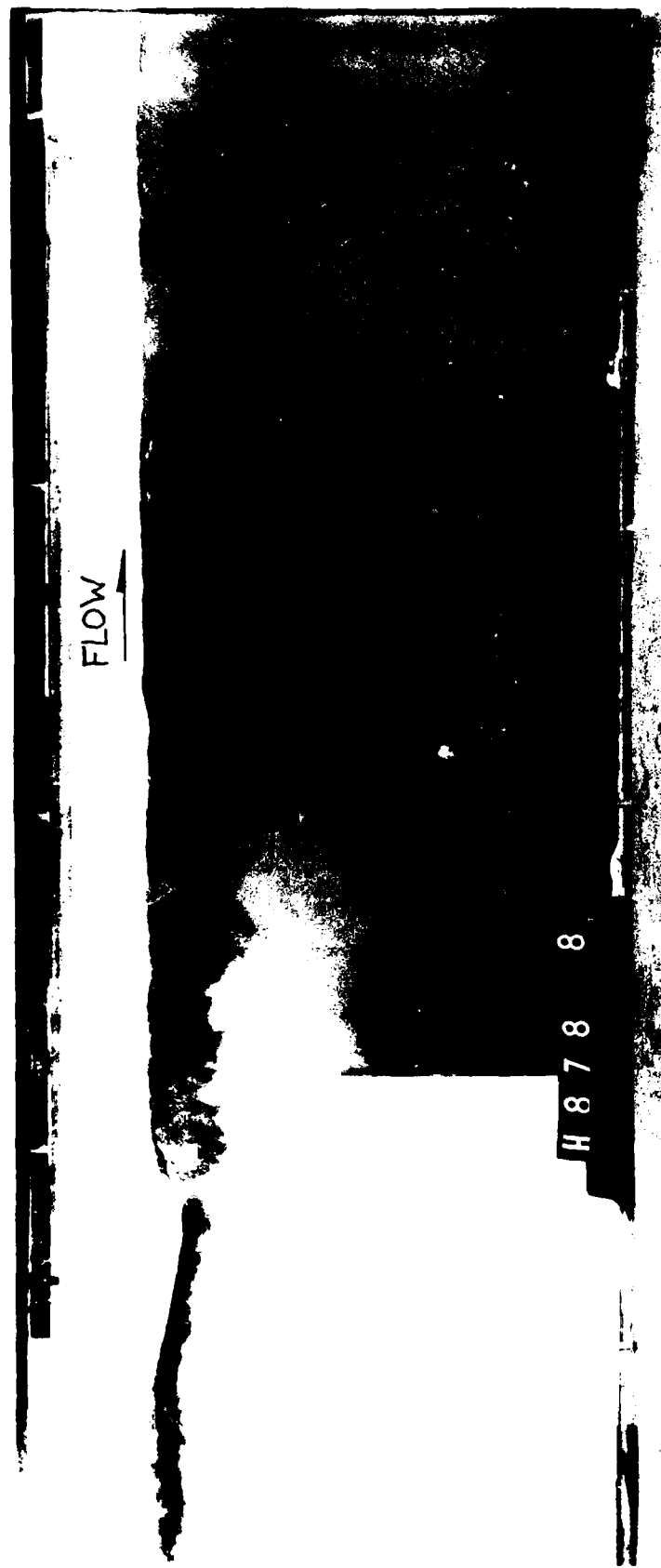


Photo 6. Flow conditions with Type 2 riprap plan; discharge 135,000 cfs, tailwater el 741.6

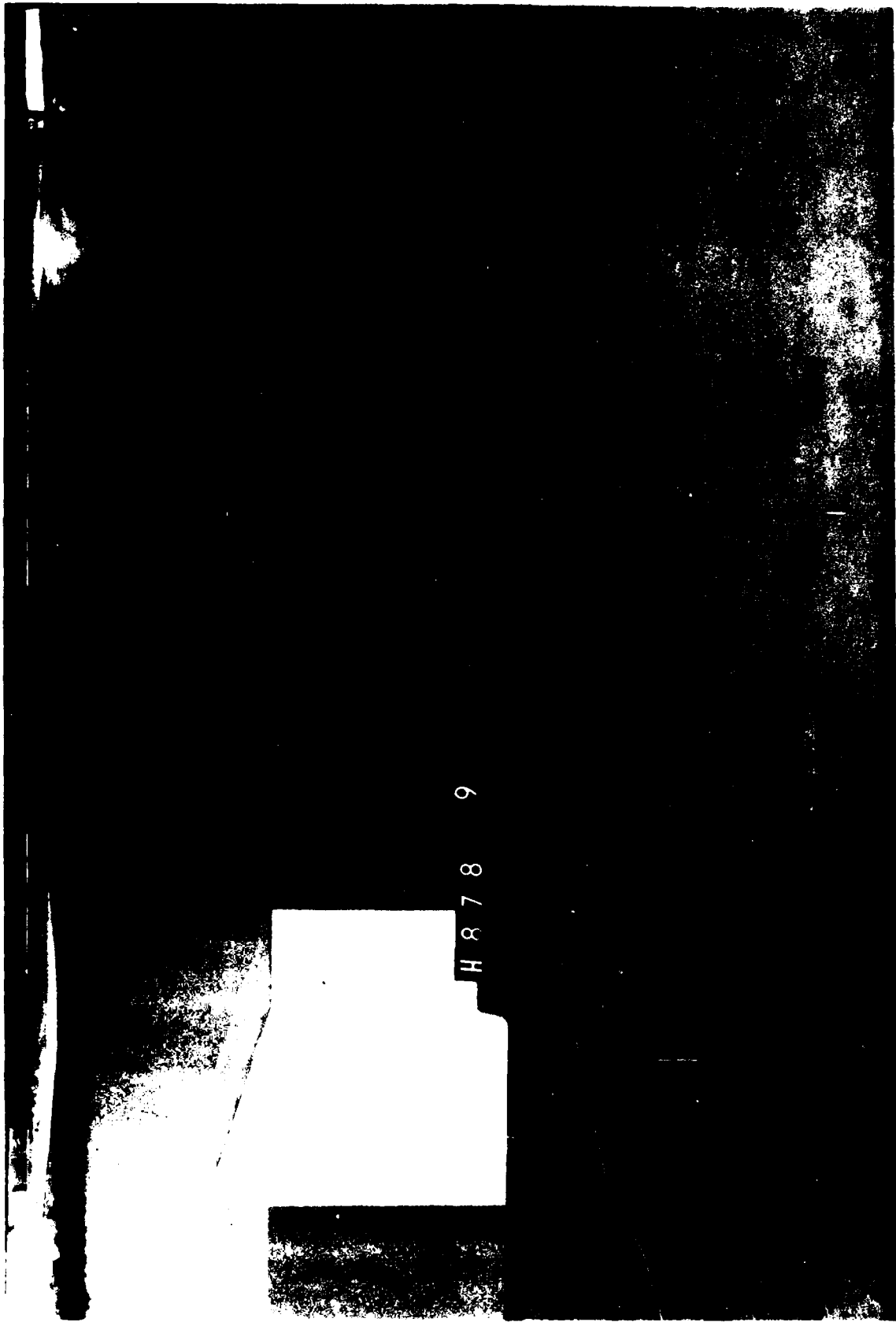


Photo 7. Flow conditions with Type 2 riprap plan; discharge 185,000 cfs, tailwater el 750.3

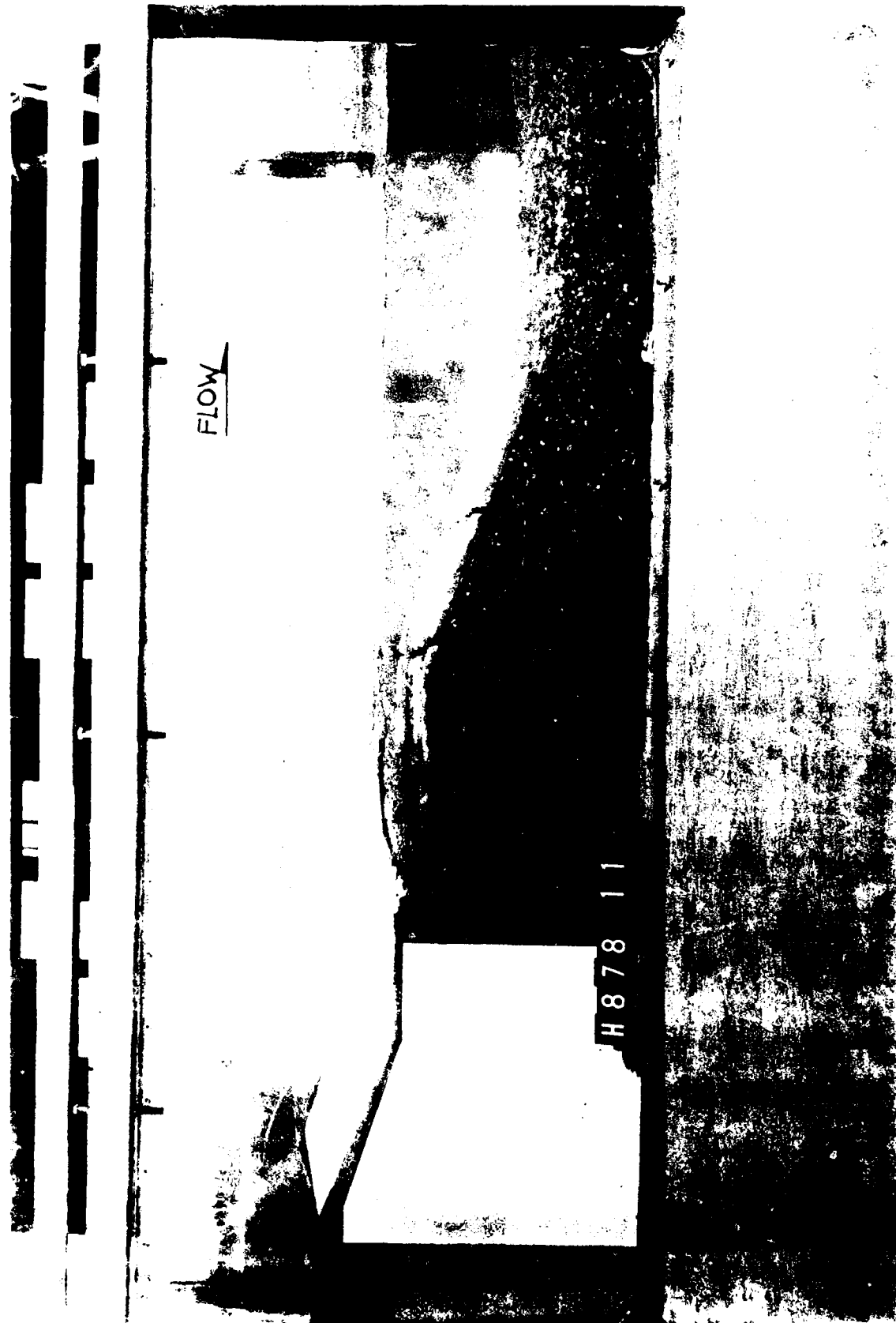


Photo 8. Flow conditions with Type 7 scour protection plan; discharge 15,000 cfs, tailwater el 722.6



Photo 9. Flow conditions with Type 11 scour protection plan; discharge 50,000 cfs, tailwater el 728.1



Photo 10. Flow conditions with Type 7 scour protection plan; discharge 70,000 cfs, tailwater el 731.2



Photo 11. Flow conditions with Type 7 scour protection plan; discharge 70,000 cfs, tailwater el 737.1

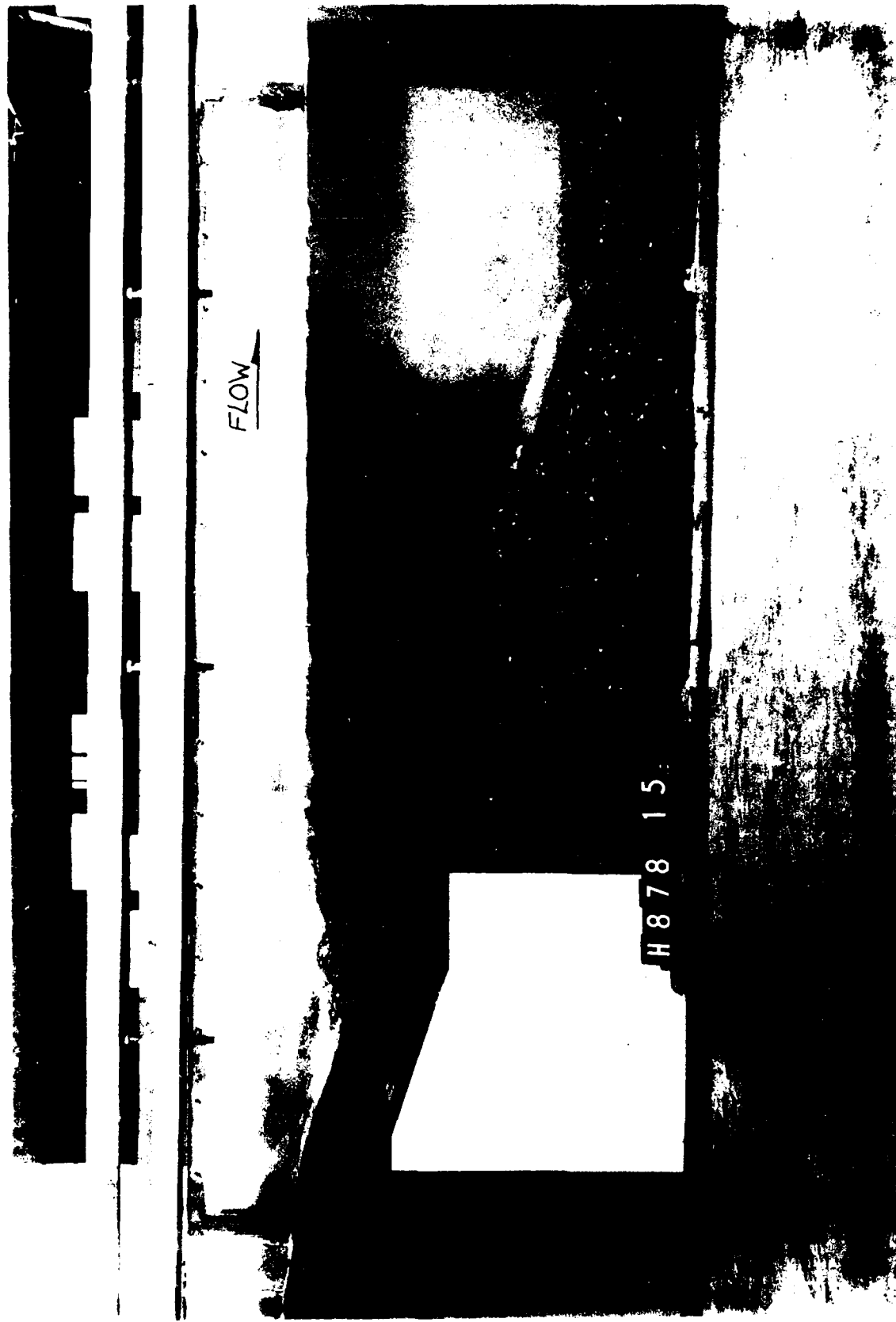


Photo 12. Flow conditions with Type 7 scour protection plan; discharge 125,000 cfs, tailwater el 739.0

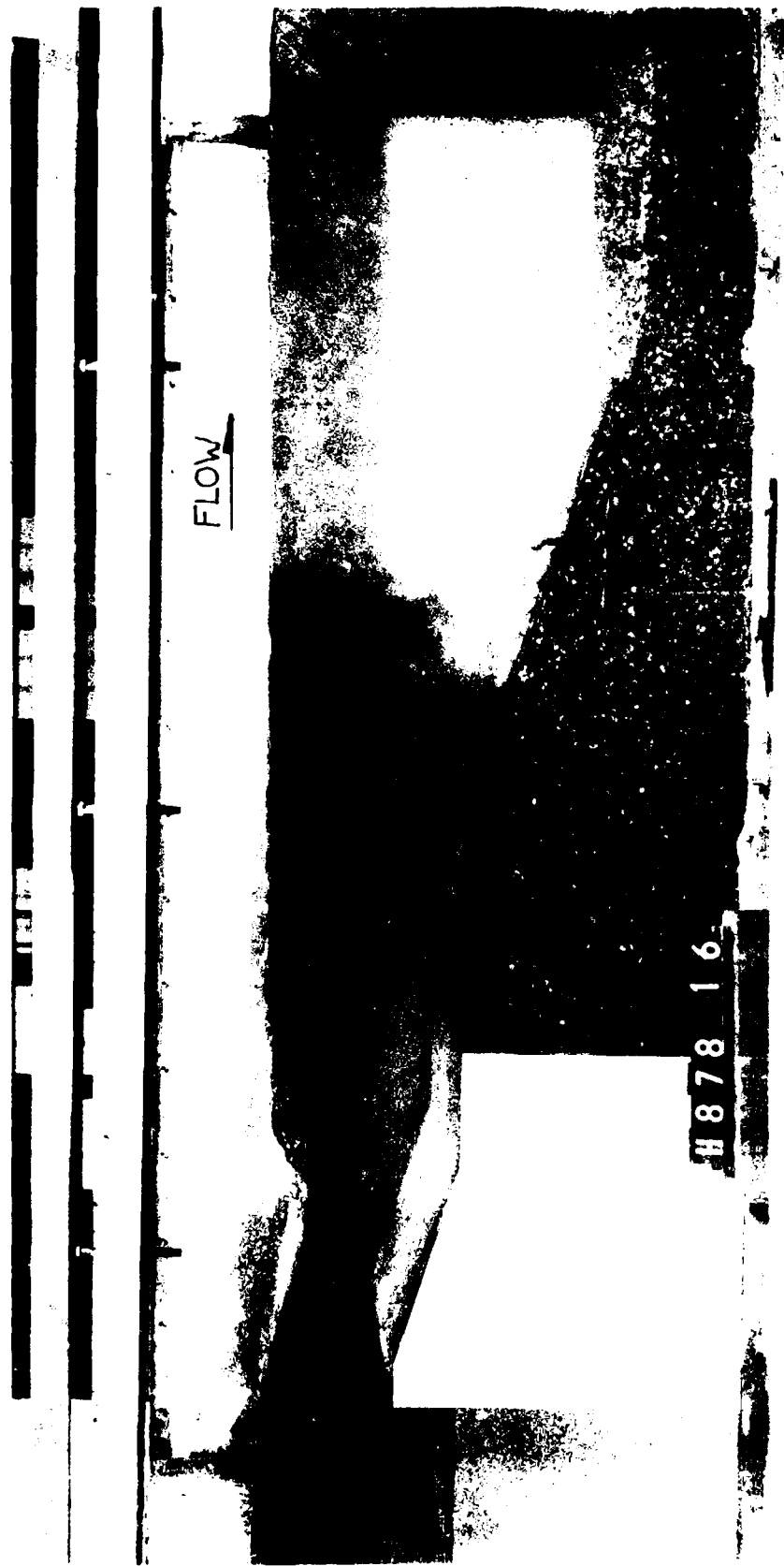


Photo 13. Flow conditions with Type 7 scour protection plan; discharge 135,000 cfs, tailwater el 741.6



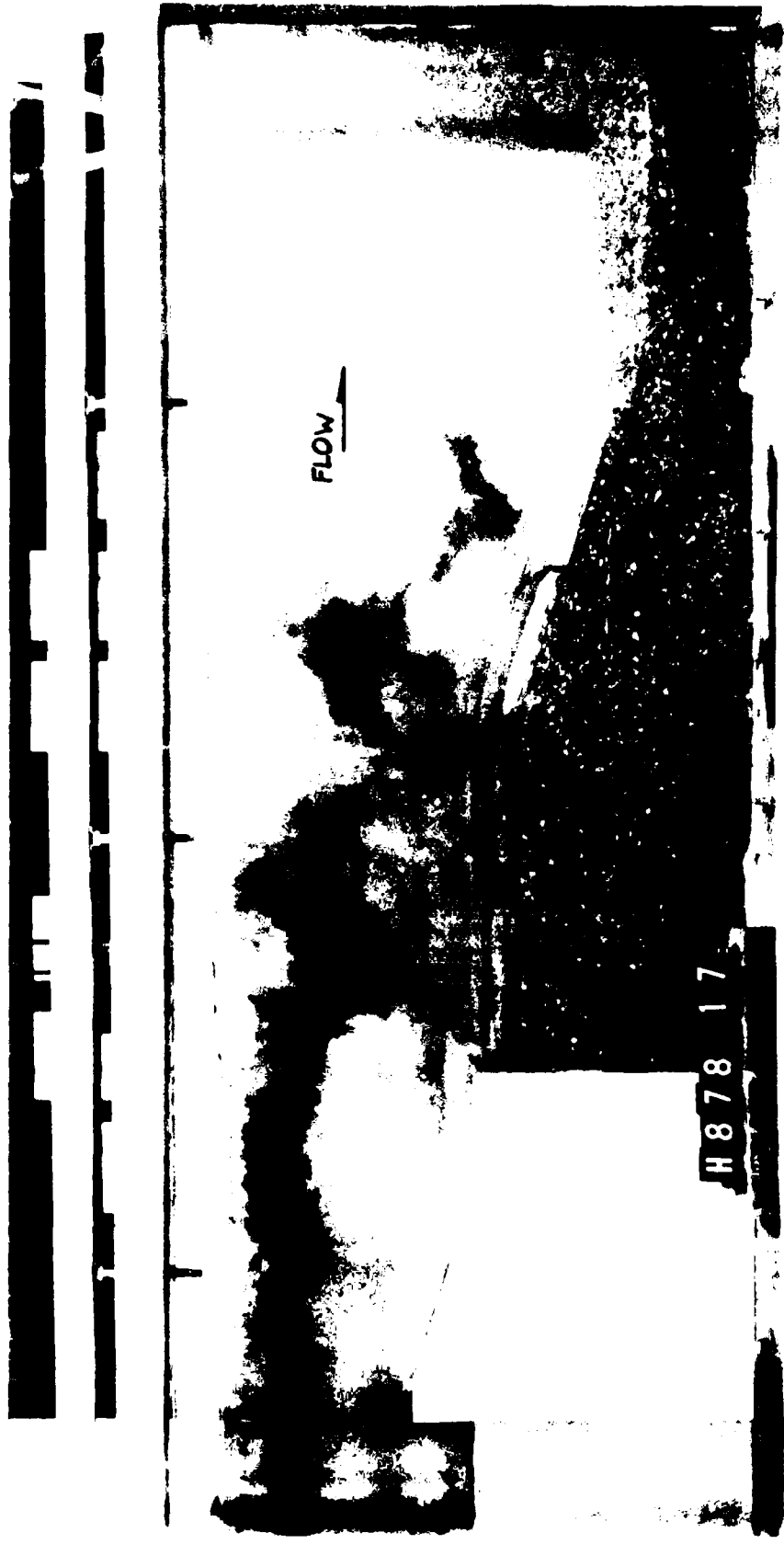


Photo 14. Flow conditions with Type 7 scour protection plan; discharge 185,000 cfs, tailwater el 750.3

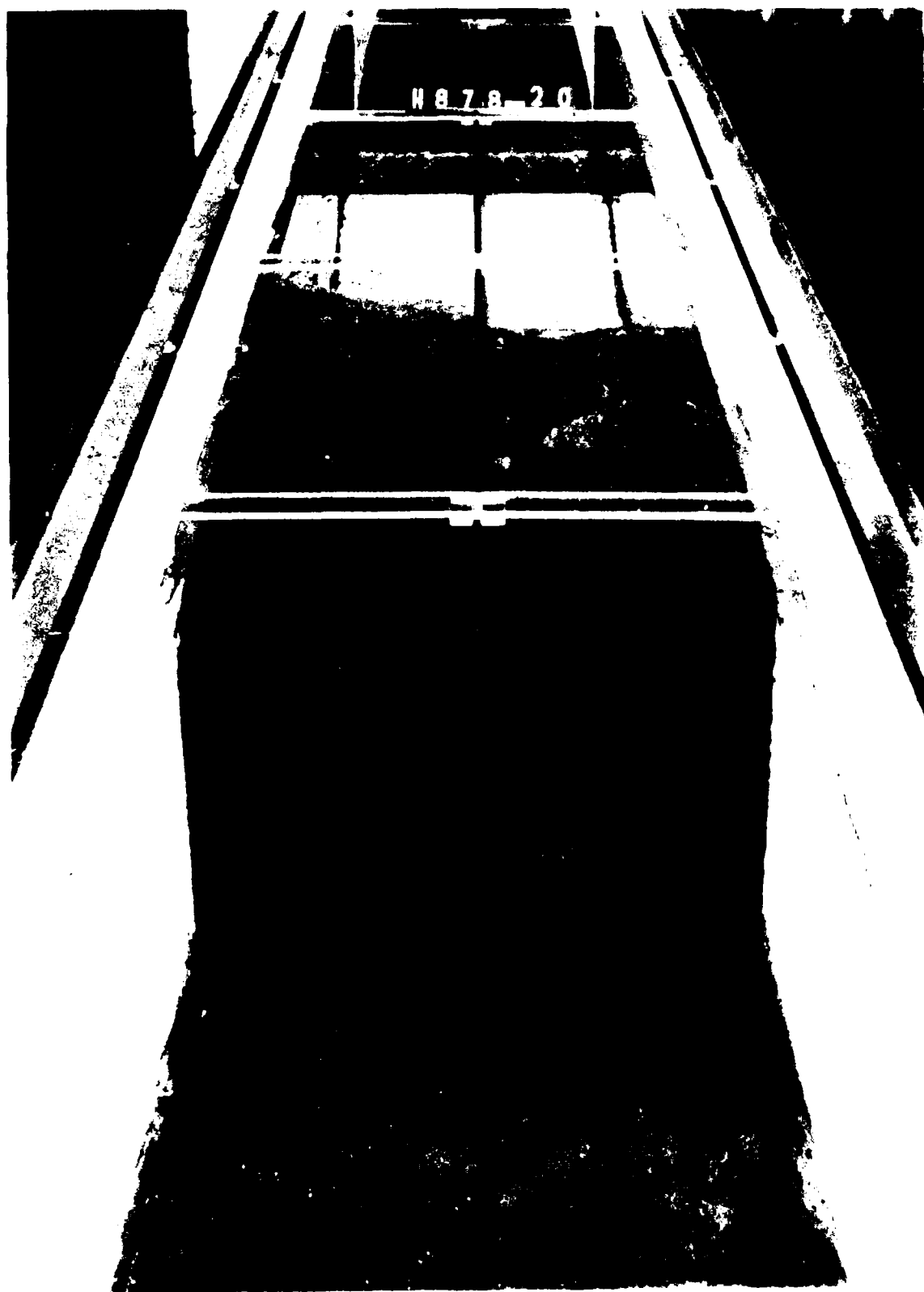


Photo 15. Simultaneous flow conditions with Type 2 riprap plan (left) and Type 7 scour protection plan (right); discharge 50,000 cfs, tailwater el 728.1

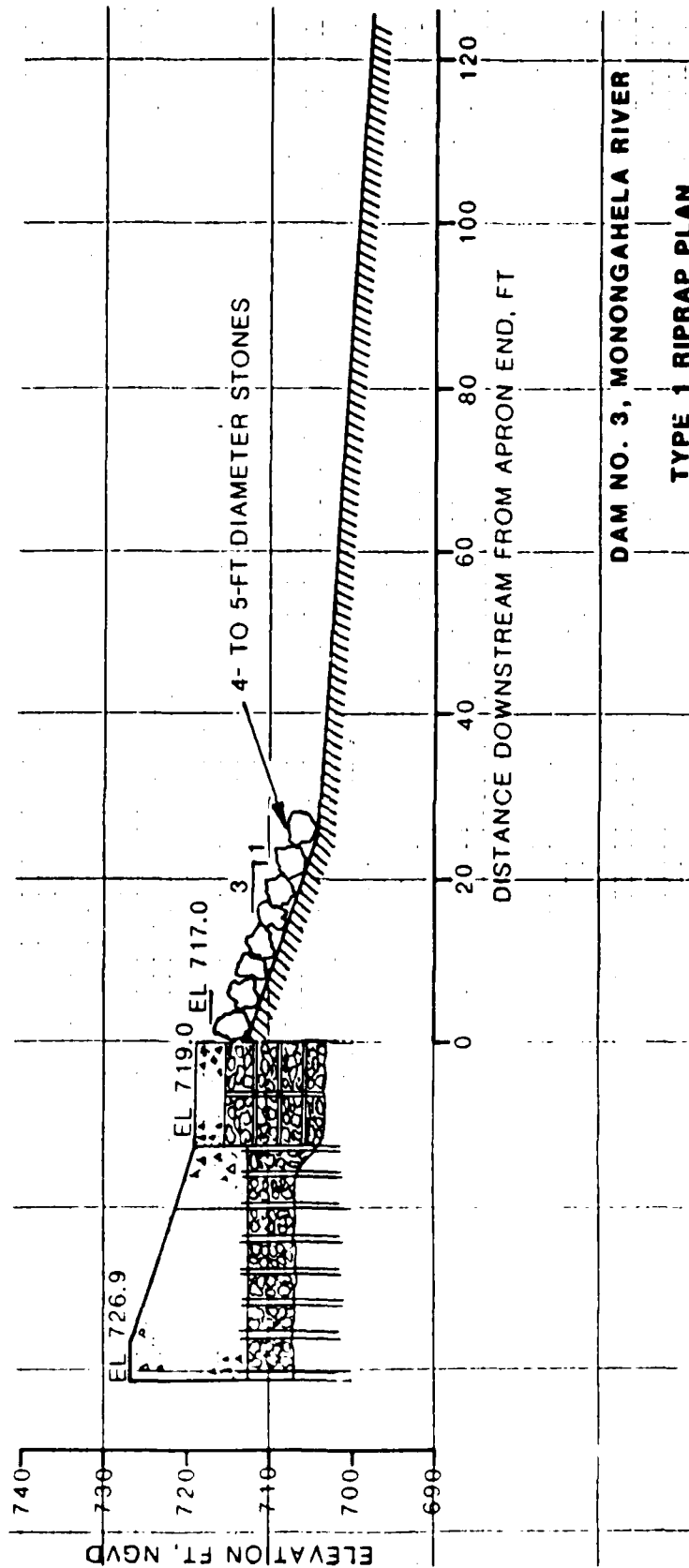
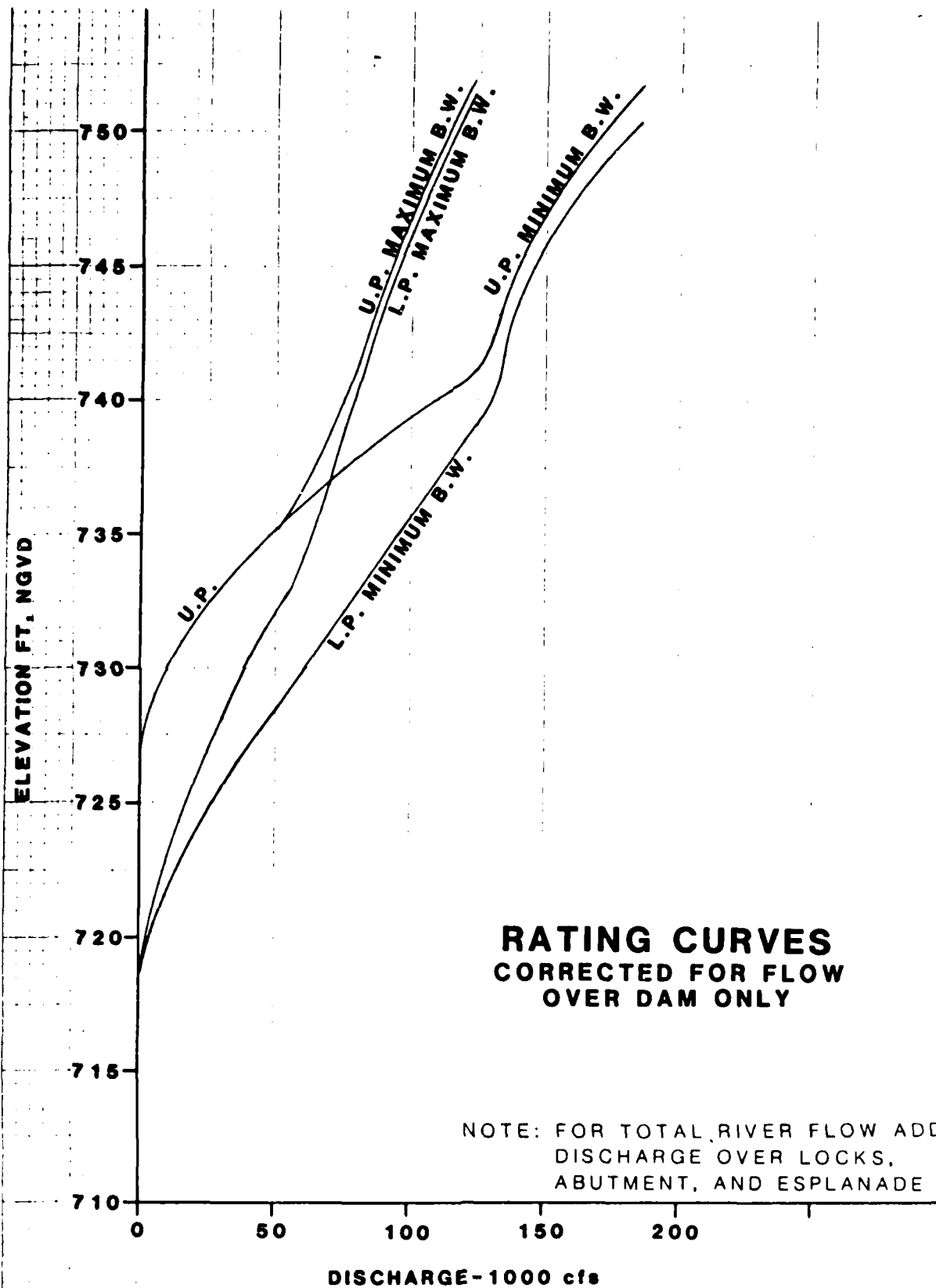


PLATE 1



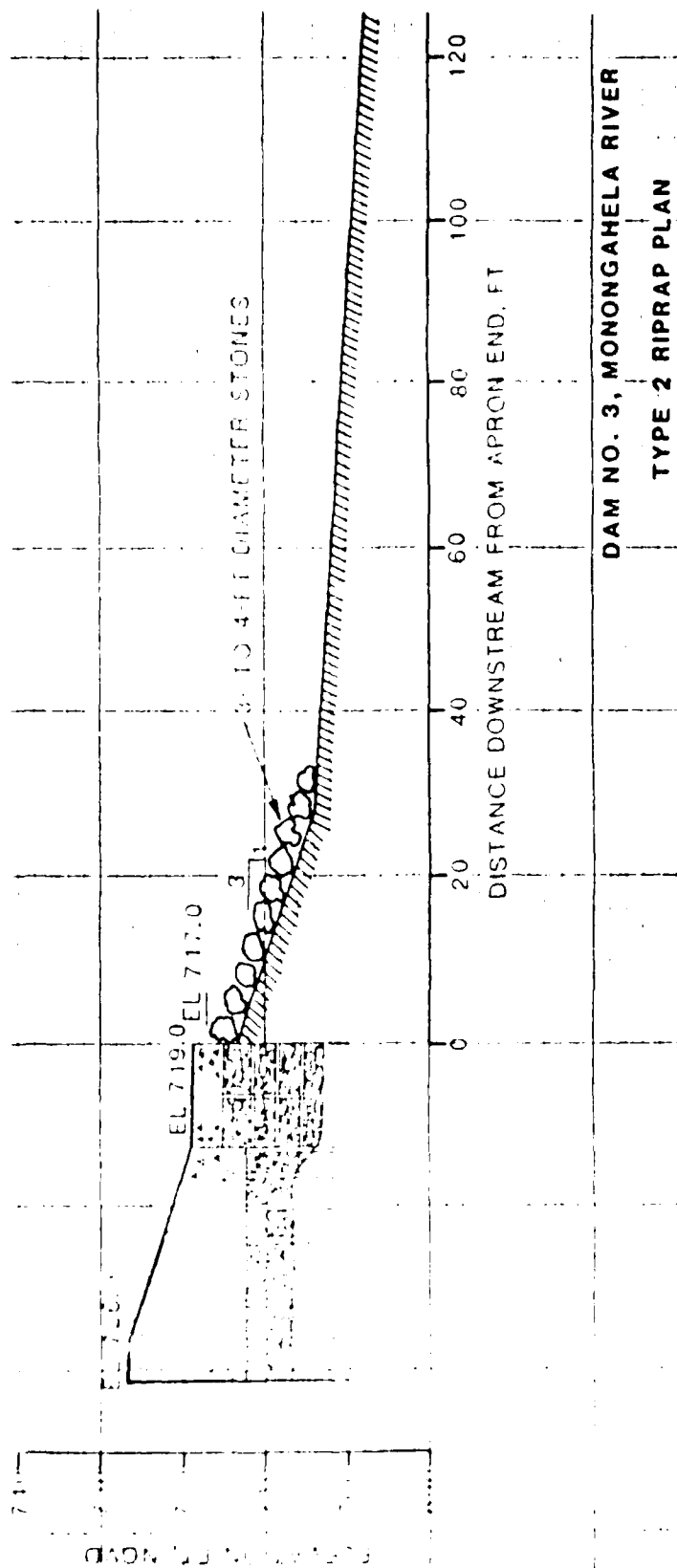
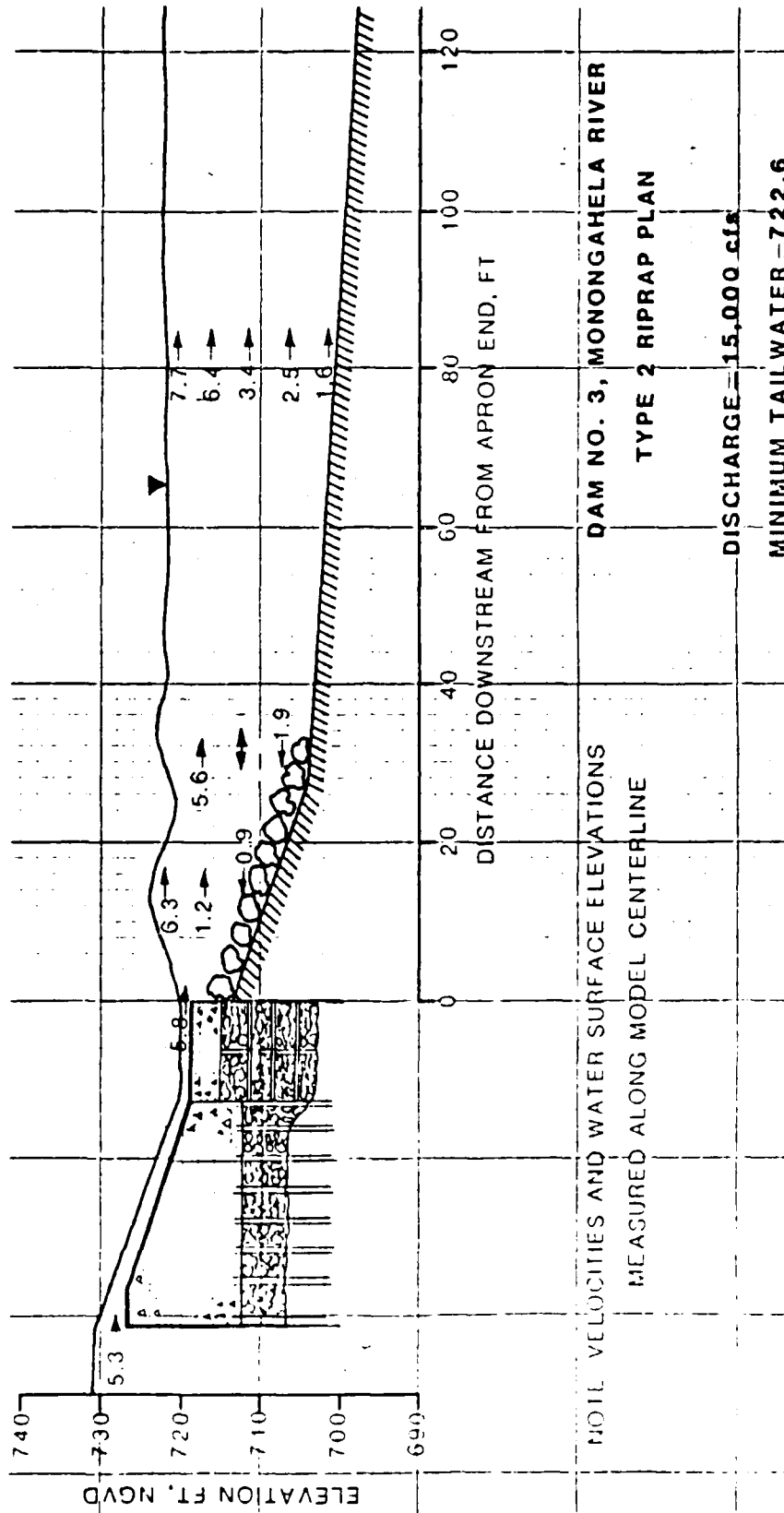


PLATE 3

PLATE 4



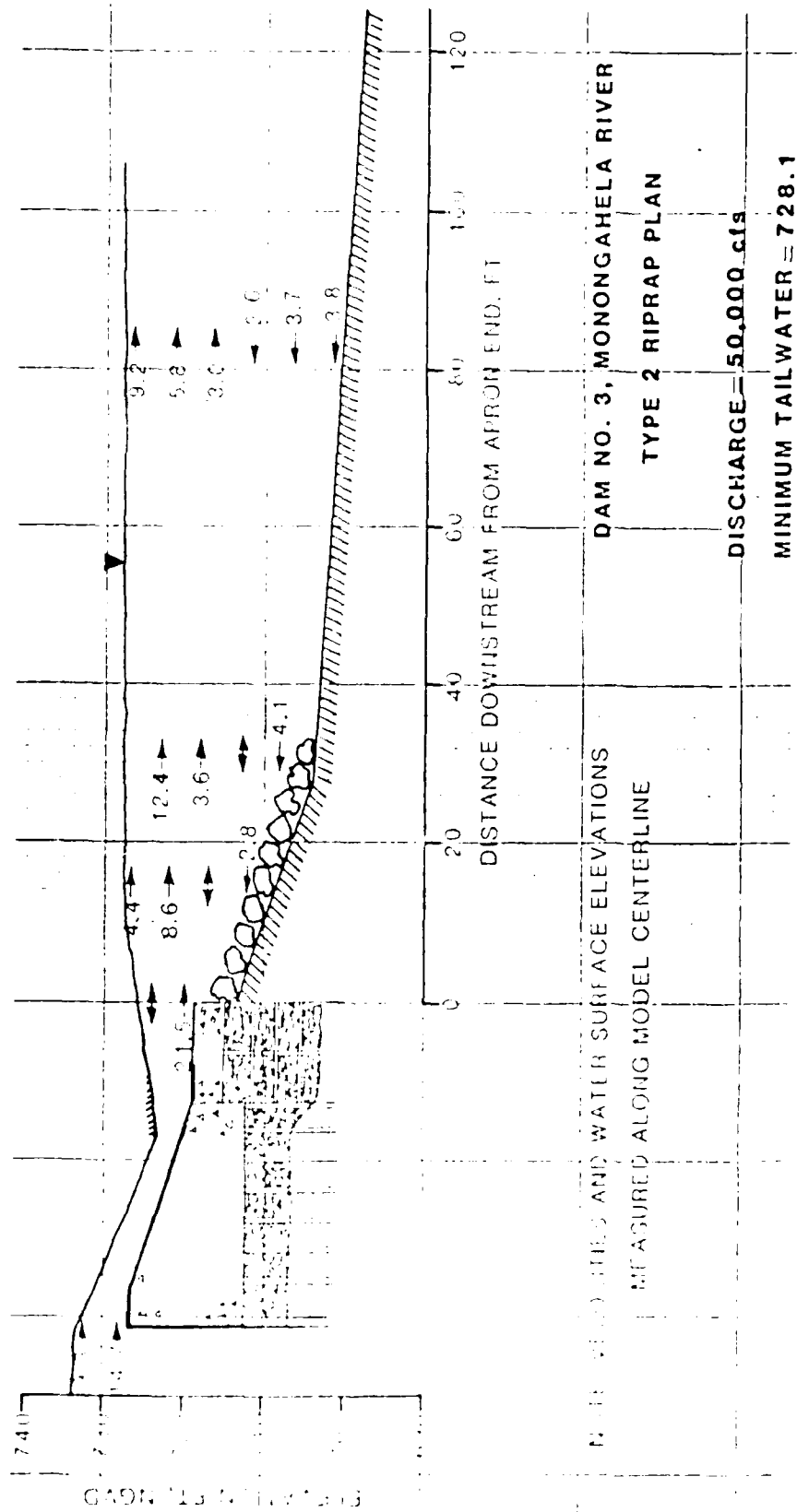
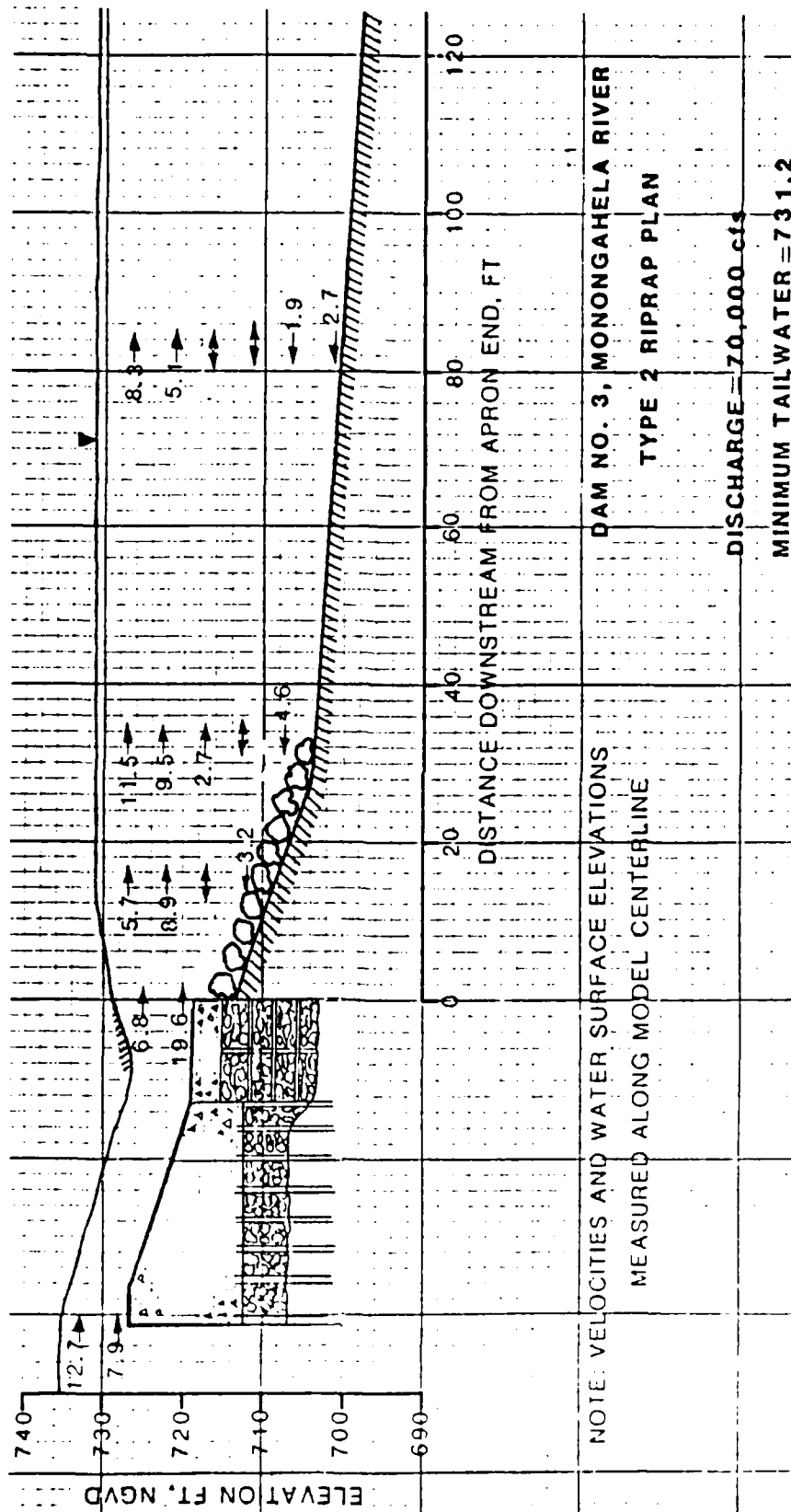


PLATE 6





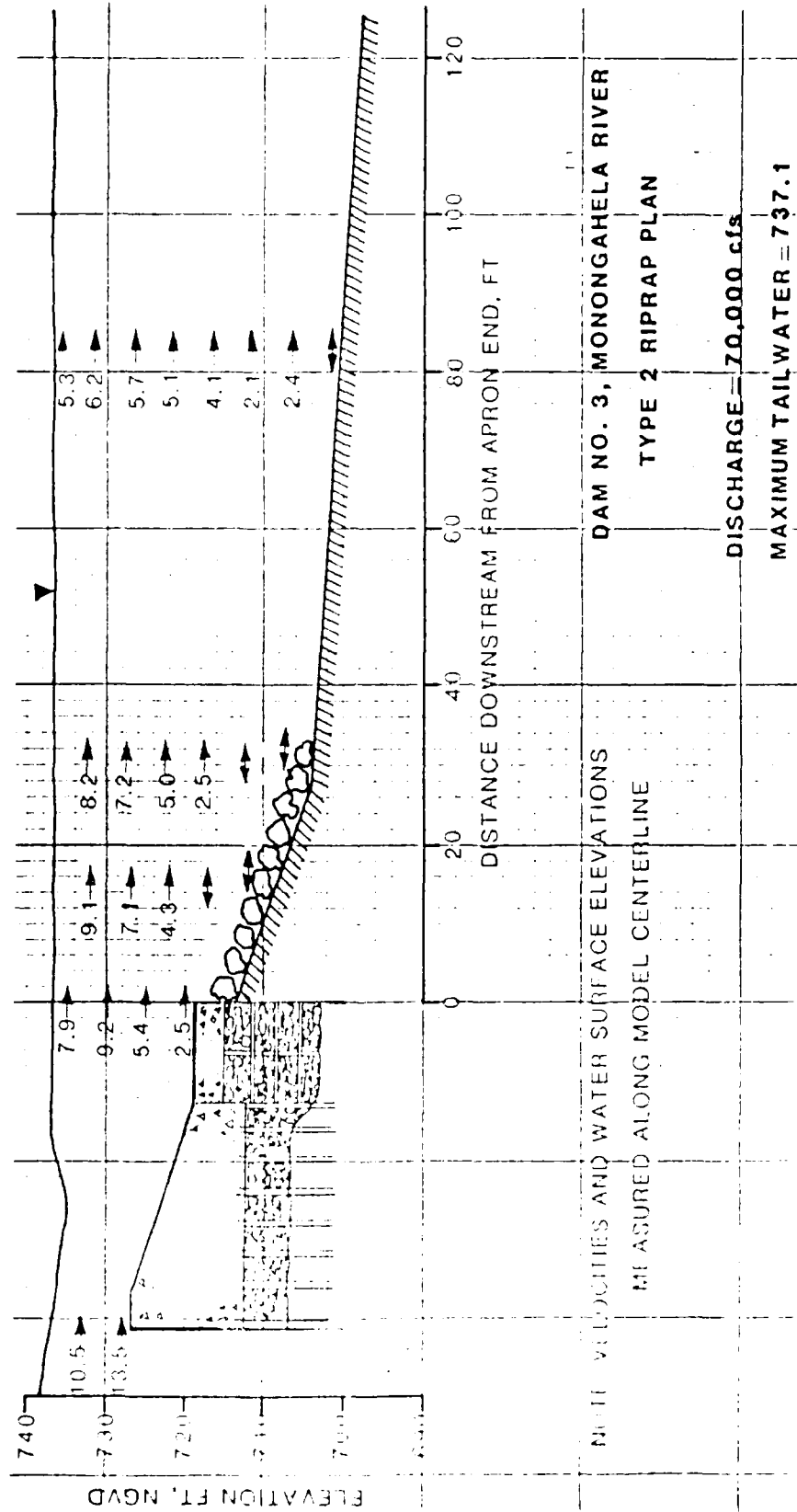
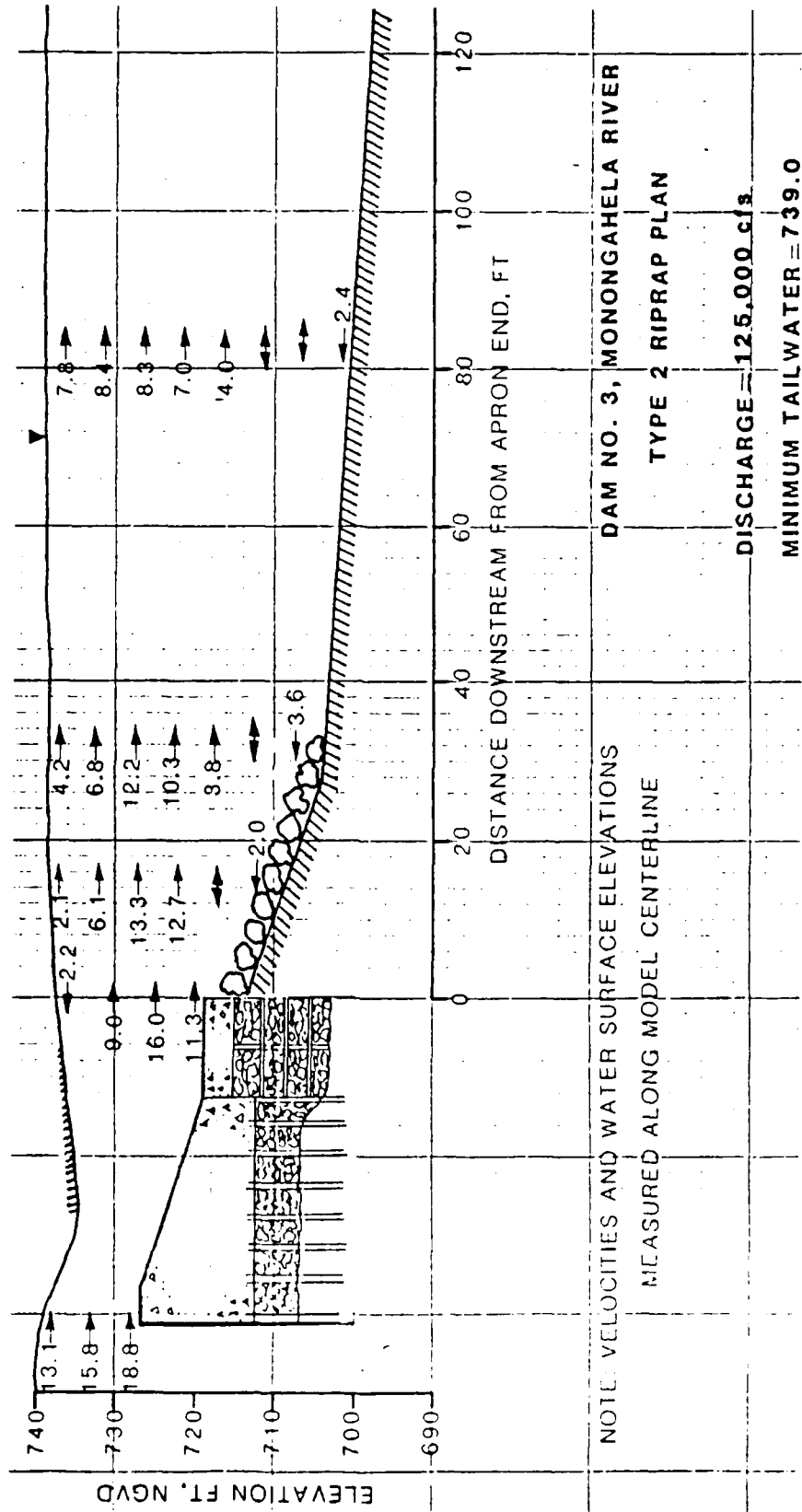


Plate 7

PLATE 8



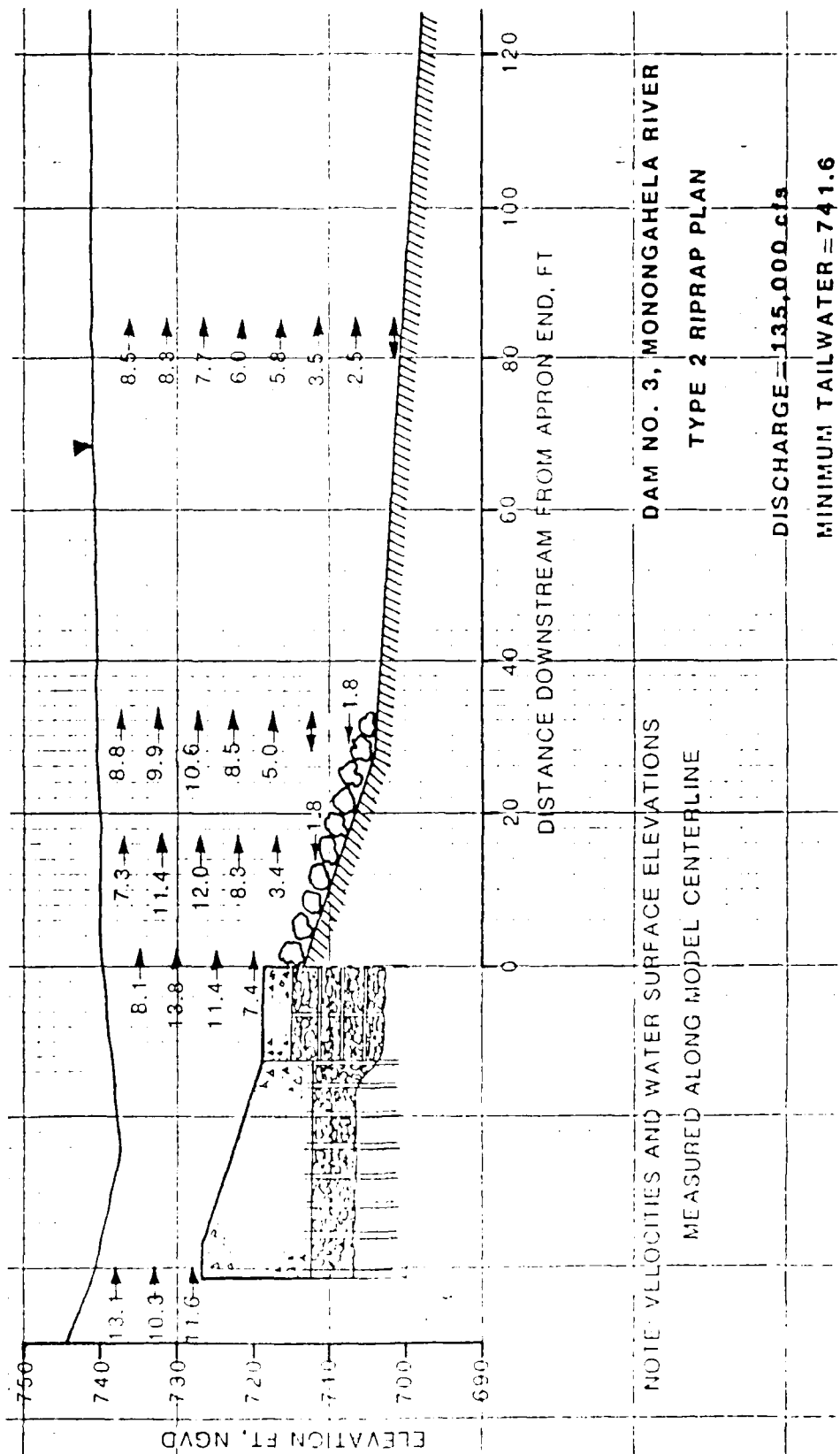
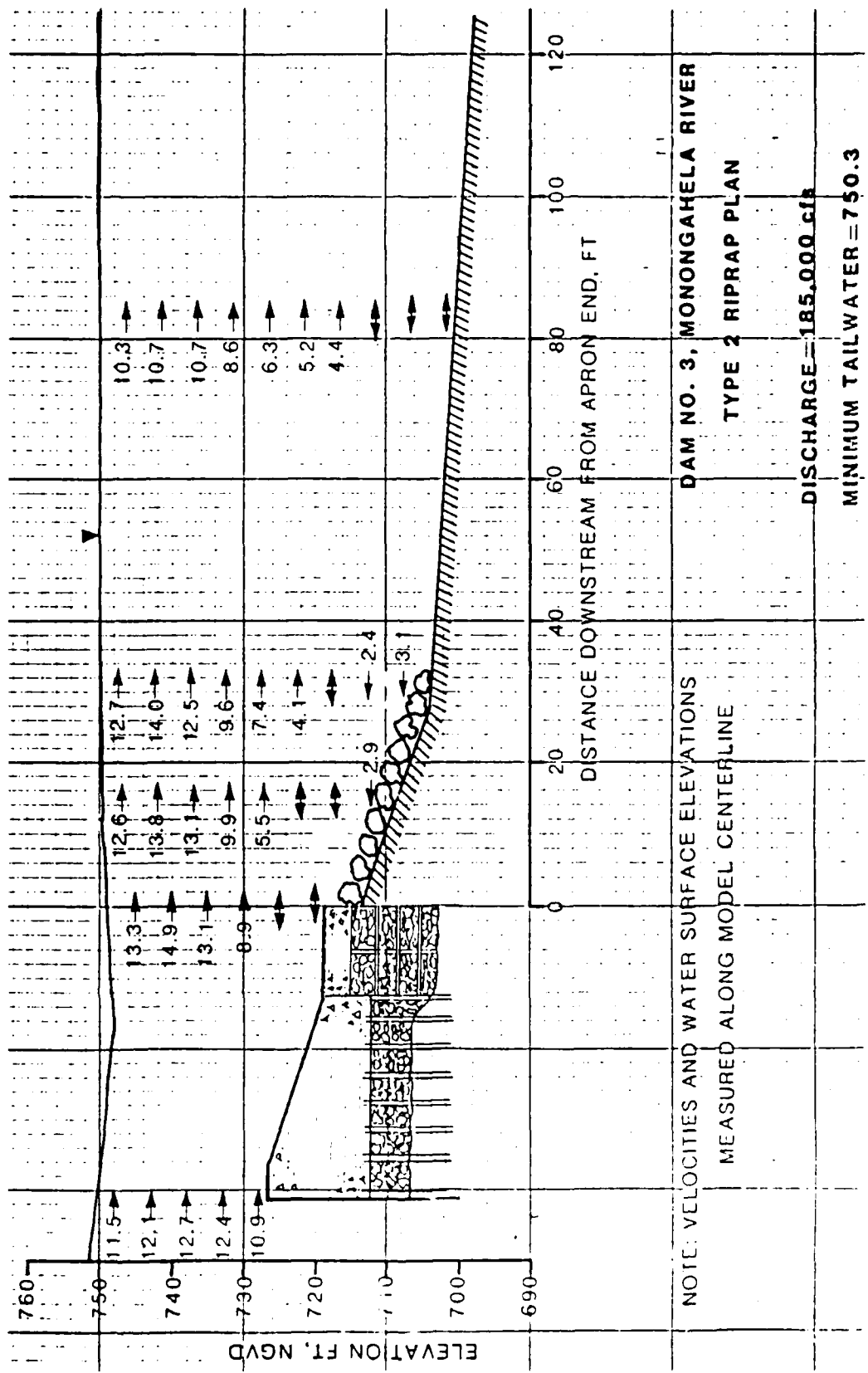


PLATE 10



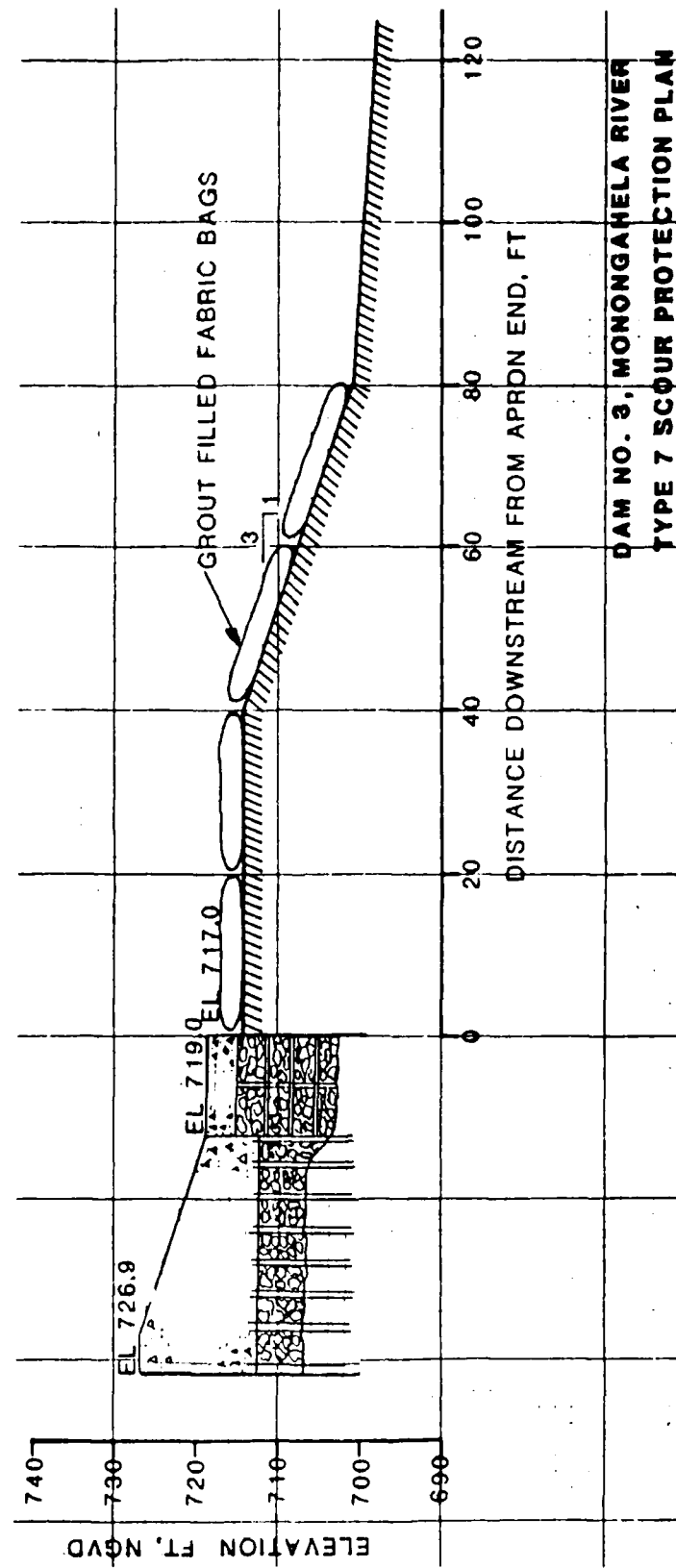
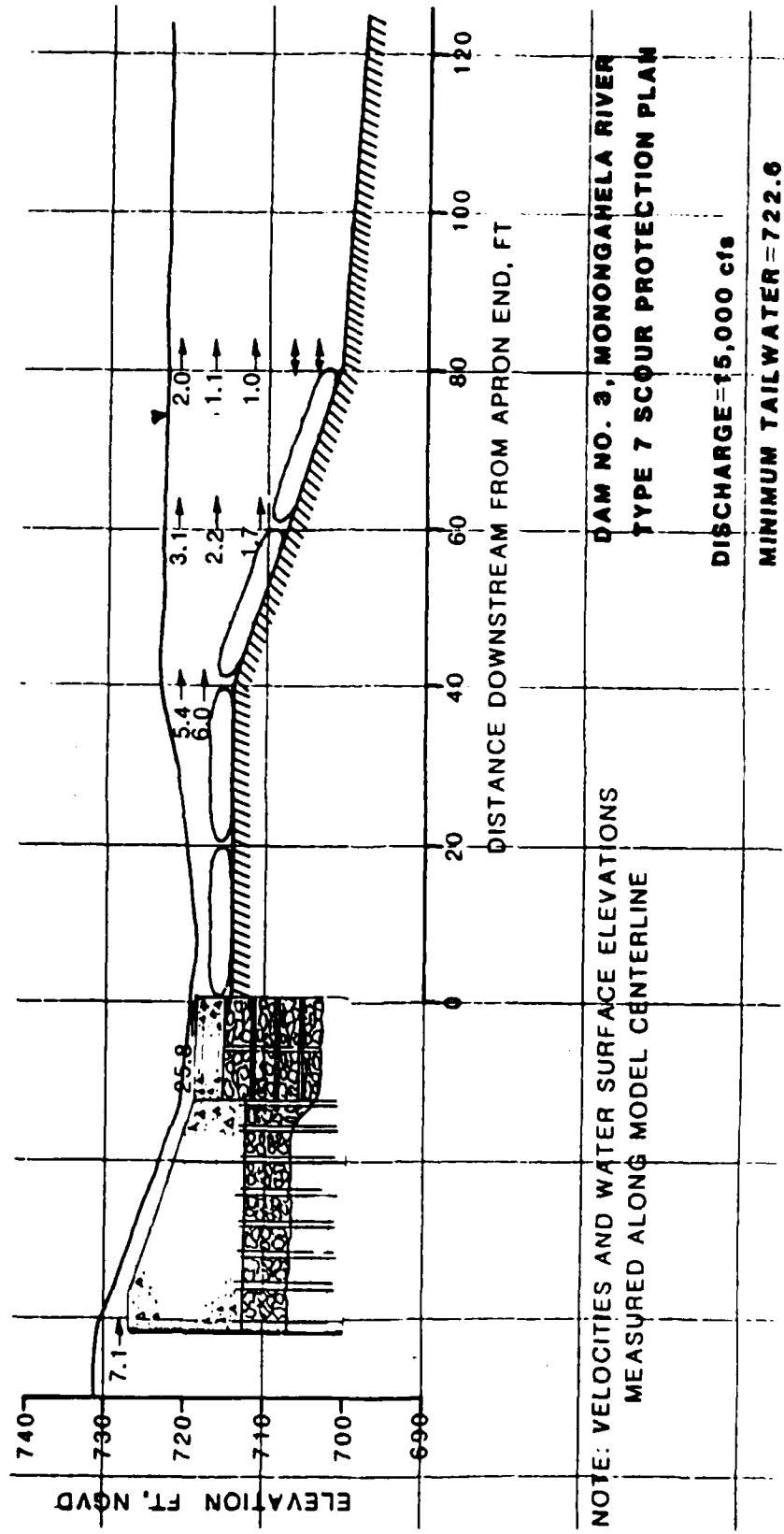


PLATE 12



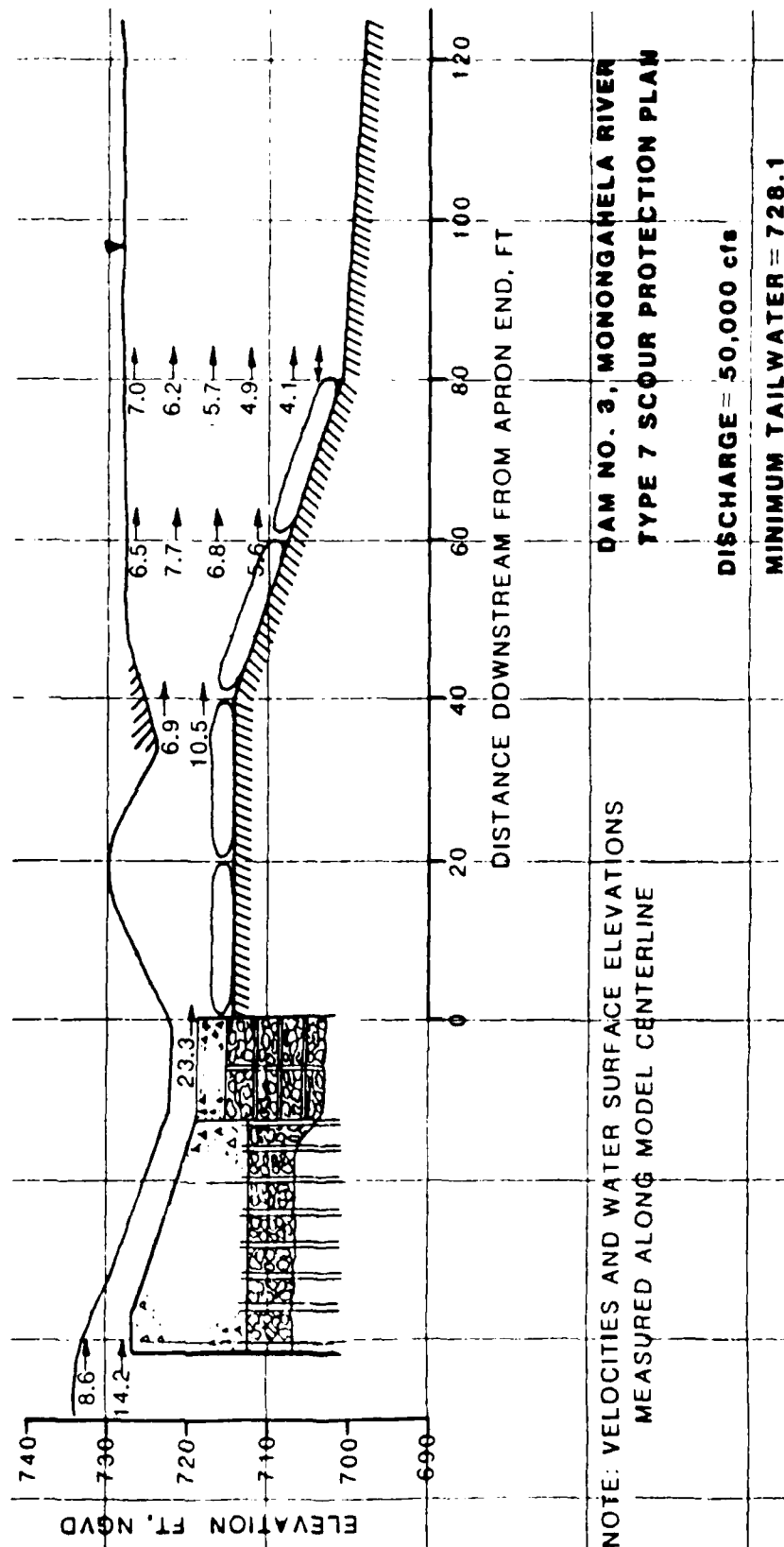
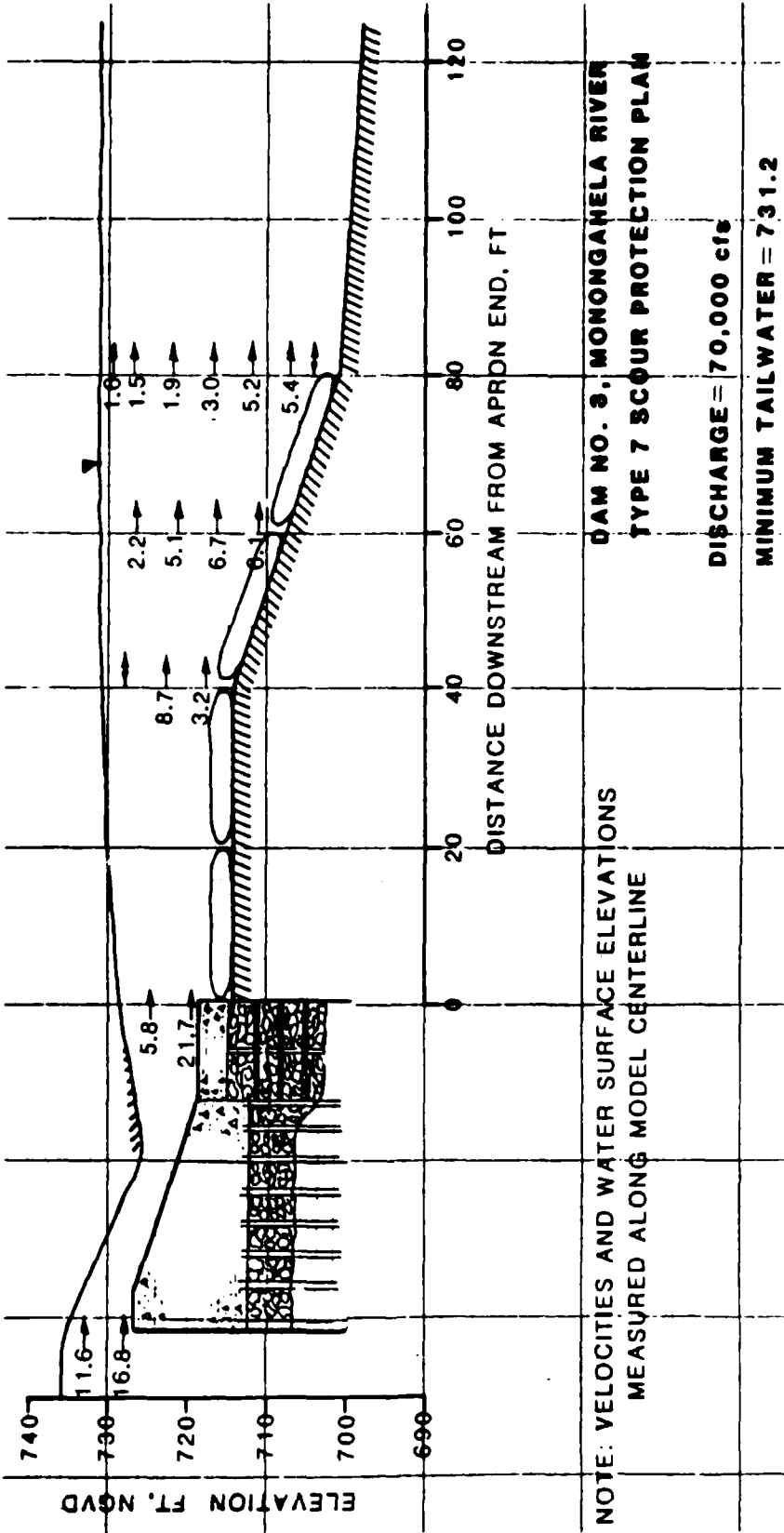


PLATE 14





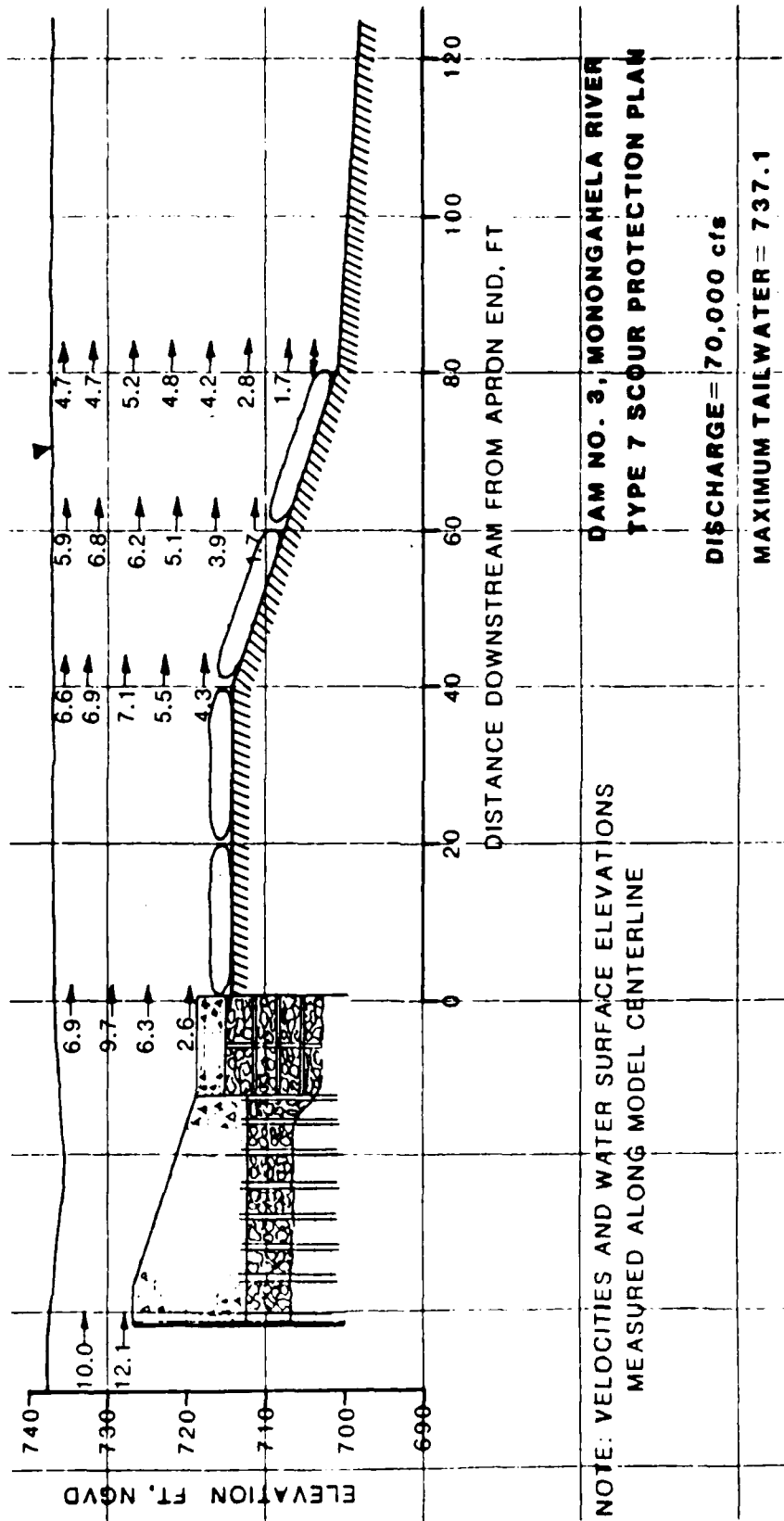
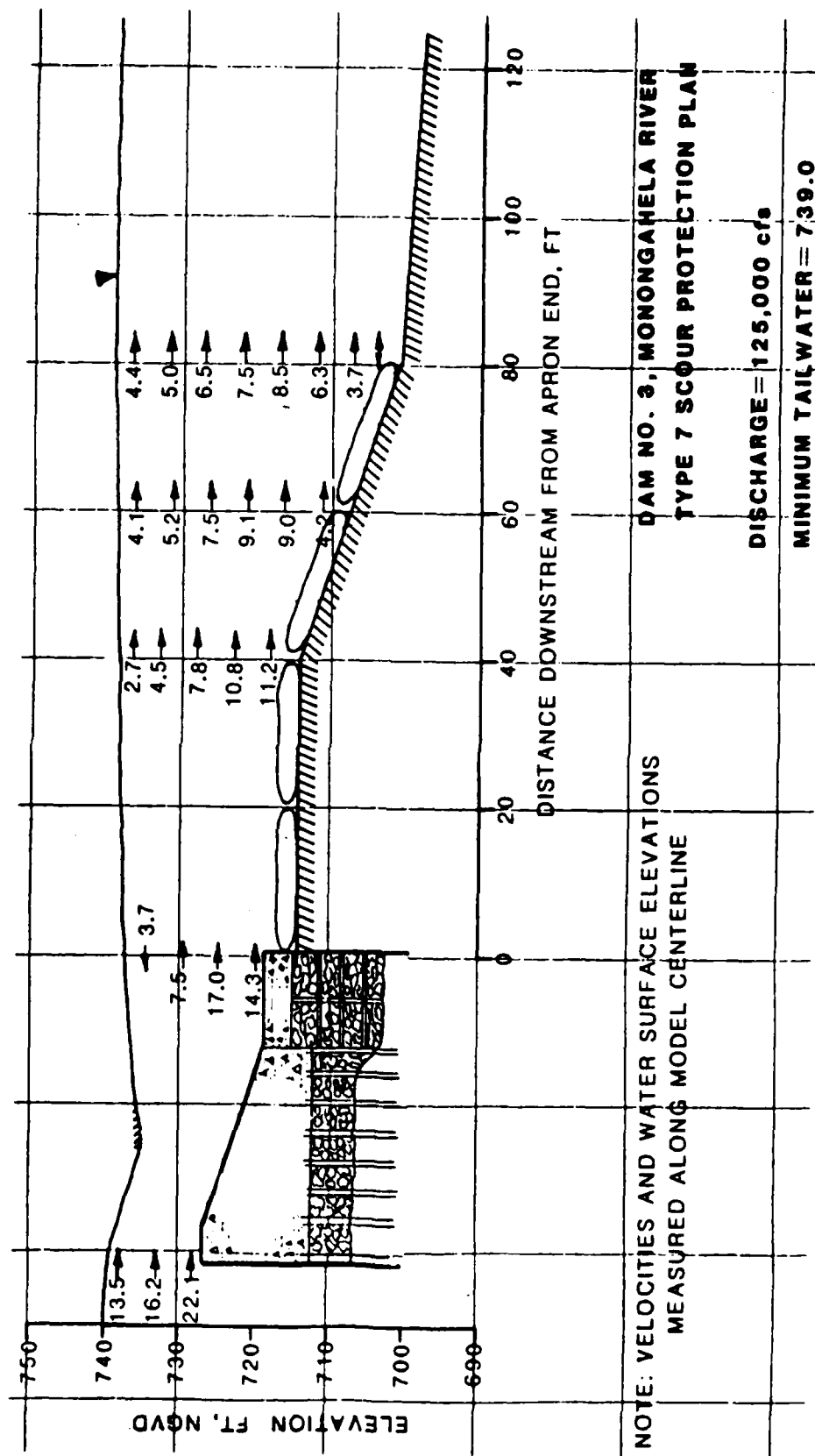


PLATE 16



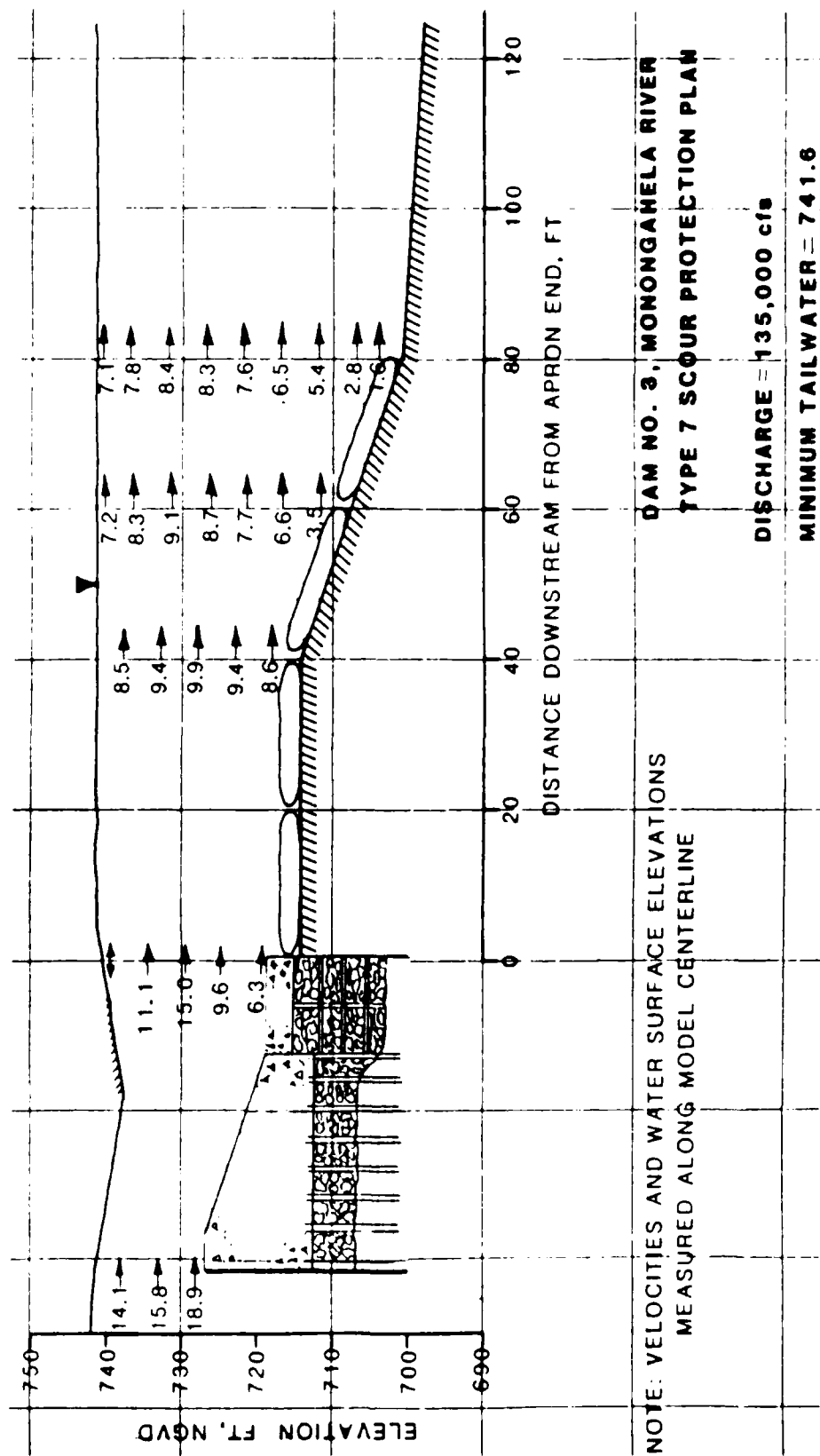
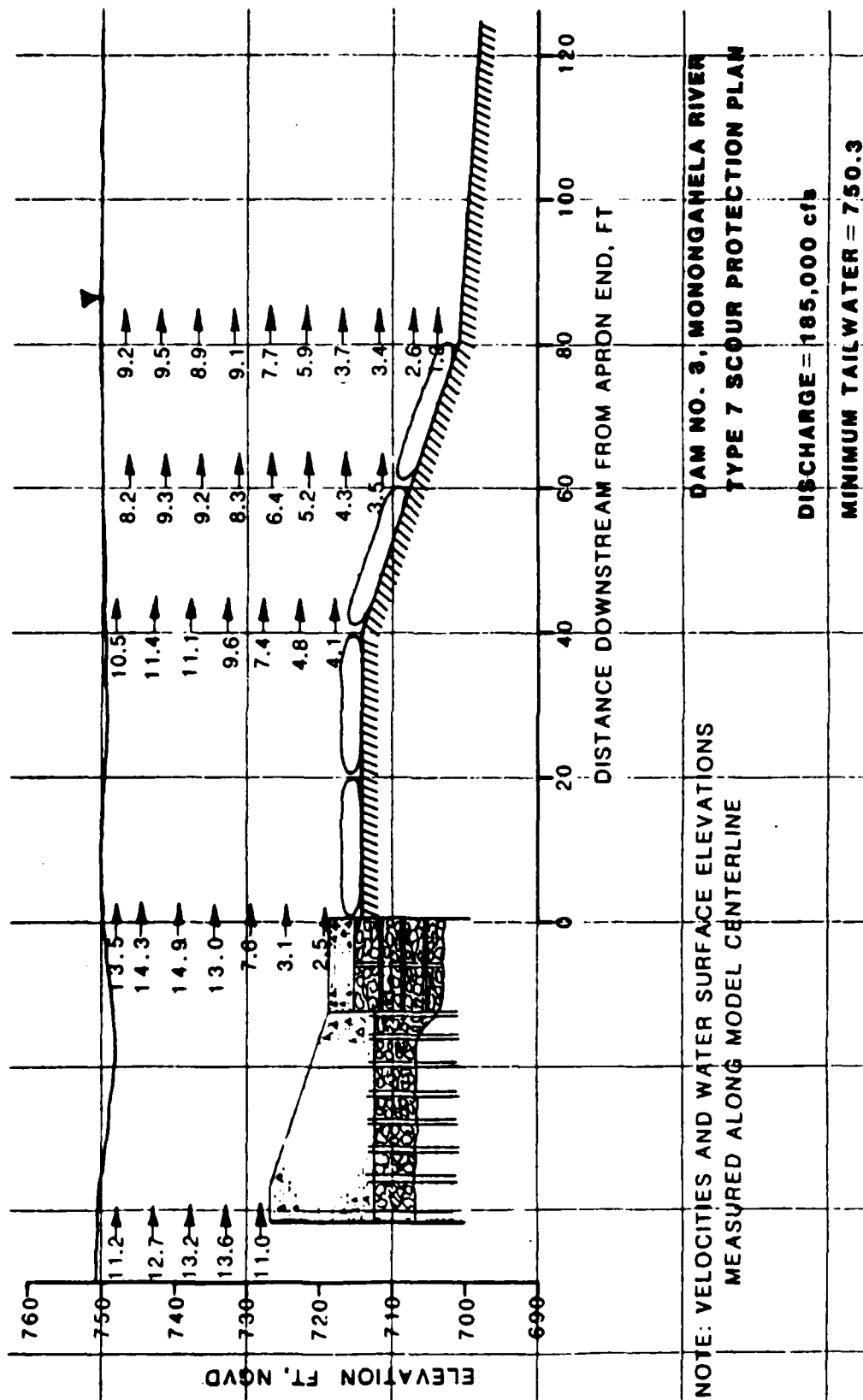


PLATE 18



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